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DYNAMIC AIR TRAFFIC CONTROL SIMULATION OF PROFILE DESCENT AND H--ETC(U)
MAY 80 P J O'BRIEN, F M WILLETT, L TOBIAS

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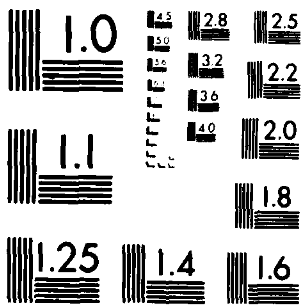

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Report No. FAA-RD-80-12
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DYNAMIC AIR TRAFFIC CONTROL SIMULATION OF PROFILE DESCENT AND HIGH-SPEED APPROACH FUEL CONSERVATION PROCEDURES

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FINAL REPORT

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16. Abstract
A dynamic simulation of instrument flight rule (IFR) air traffic operations in the Denver, Colorado, terminal area was conducted at the National Aviation Facilities Experimental Center (NAFEC) to investigate aircraft fuel conservation procedures and the compatibilities of these procedures with air traffic control (ATC) and with the expeditious flow of air traffic. The laboratory environment of the NAFEC Air Traffic Control Simulation Facility (ATCSF) was utilized along with two Ames Research Center (ARC) piloted flight simulators. The ARC simulators were interfaced with the ATCSF via a landline system and were flown within the simulated environment together with the NAFEC computer-generated flights. Fuel conservative procedures tested were the profile descent and two high-speed approaches, the delayed flap approach and the International Air Transport Association (IATA) approach. The Denver terminal radar approach control (TRACON) was simulated, and traffic was representative of Stapleton Airport IFR operations. Results showed that, by comparison with conventional procedures, fuel was saved when only the profile descent procedure was used. Fuel saving with the high-speed approach procedures, as simulated, was questionable. There was an indication of a fuel saving when departure flights were not restricted to maintaining 250 knots at 10,000 feet and below. Additionally, a graphic study showed that, at landing gross weight conditions, the most desirable holding altitudes were between 20,000 and 30,000 feet. A more in-depth study of the ramifications of computer-aided flight scheduling and latest technology in fuel saving flight procedures is recommended.

17. Key Words
Fuel conservation
Profile descent
IATA approach
Delayed flap

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PREFACE

This simulation was intended to be a fact-finding and concept investigation study with the results, together with the benefits from the evolution of research, providing background for more sophisticated simulations of fuel conservation and attendant air traffic control procedures at later dates.

The work effort was accomplished within the National Aviation Facilities Experimental Center (NAFEC) Systems Test Branch under NPD No. SE-191, ATC Operational Sustaining Engineering; Subprogram No. 218-150, FAA/NAFEC - NASA/Ames ATC simulations. The Washington Subprogram Manager was Joseph P. O'Brien, ARD-100; the NAFEC Program Manager was Felix F. Hierbaum, ANA-210; the Ames Program Manager was Dr. Heinz Erzberger, and the NAFEC and Ames Project Managers were P. James O'Brien and Dr. Leonard Tobias, respectively.

Acknowledgment is extended to Mr. John J. Ryan, NAFEC project pilot, for a fine effort in conducting the graphic study of the holding configuration fuel flow of large turbojet aircraft contained in this report.

The authors also wish to acknowledge Messrs. Pierre E. Collins, Ralph C. Miller, and Victor J. Misiewicz (Air Traffic Control Specialists) for their contributions and able assistance as members of the NAFEC project team. Acknowledgment is also extended to Messrs. Barry R. Billmann and Thomas E. Morgan of Computer Sciences Corporation for providing the statistical test design, data analysis, and counsel during the planning and testing periods.

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INTRODUCTION

PURPOSE.

The purpose of this project was to investigate aircraft fuel conservative procedures using dynamic simulation techniques. The specific objectives were to dynamically simulate the Denver, Colorado, terminal area air traffic environment and collect and analyze fuel consumption and other pertinent data in order to study the effects on traffic flows and the air traffic system of two fuel conservative procedures; namely, profile descent and high-speed approaches.

BACKGROUND.

The present joint Federal Aviation Administration/National Aeronautics and Space Administration (FAA/NASA) efforts, accomplished by the National Aviation Facilities Experimental Center (NAFEC) and the Ames Research Center (ARC) have been continuous over the past 4 years under an interagency research program. In cooperation with the Washington FAA System Research and Development Service (SRDS) Office, NAFEC and ARC have interconnected the air traffic control (ATC) simulation facilities at both centers with the piloted simulation facilities at ARC to create a unique national facility. Three ATC dynamic simulations have been conducted; two small-scale simulations at ARC using an ARC in-house simulation capability, and one full-scale simulation at NAFEC using the NAFEC Air Traffic Control Simulation Facility (ATCSF).

The current energy situation, typified by fuel shortages and rising costs, has mandated that aircraft fuel conservation programs be undertaken, geared toward the development of in-flight aircraft operational procedures providing greater fuel economy than previously achieved. Several studies have been made and procedures developed. One of the most familiar fuel conservation procedures developed has been profile descent. Profile descent provides for an idle-thrust descent from cruise altitude/flight level until glide slope intercept. Another fuel conservative development, called high-speed approach, utilizes two procedures governing final approach speeds at normal approach altitudes. The two final approach speed procedures, the delayed flap and the International Air Transport Association (IATA) low-power noise abatement approach technique, were studied by simulation at ARC. The idle-thrust profile descent together with the delayed flap and IATA high-speed approach procedures were the subject matter of the tests in the simulation conducted at NAFEC.

DISCUSSION

GENERAL.

The subject of aircraft fuel conservation has produced much discussion, and various fuel conservative procedures have been proposed. Those considered in

this simulation were profile descents and high-speed approaches. Previous experiments have shown that each procedure saves fuel for an individual aircraft if executed as planned. However, the impact of these procedures on the ATC system has been uncertain. Satisfactory procedures must not only save fuel for the individual aircraft, but must also result in a reasonable workload for the controller and pilot. Additionally, other aircraft should not be significantly delayed nor should delay be shifted to another part of the ATC system such that the overall system fuel usage is greater.

As directed by the Operational Requirements Branch of the Washington FAA/SRDS Office, the NAFEC Systems Test Branch was charged with conducting a comprehensive dynamic simulation study of the selected aircraft fuel conservation procedures. Those procedures, together with the Denver, Colorado, terminal area, were specified as broad test requirements by the Washington SRDS Office, and the NAFEC ATCSF was used as the test facility. The profile descent and high-speed approach procedures were tested both separately and together, and baseline data for comparisons were collected when none of the fuel conservative procedures were used.

Simulation tests were conducted between July 18 and August 19, 1977. Approximately 5,000 flights were simulated during 32 test-designed data collection runs, plus eight additional runs. A graphic study was also conducted to appraise fuel consumption of selected aircraft flying in holding configurations.

SIMULATION PROCEDURES.

SIMULATION FACILITIES. The NAFEC ATCSF laboratory provided the simulation environment. The simulated ATC facility control room and the "pilots" computer entry operating positions are shown in figures 1 and 2, respectively. Two ARC-piloted aircraft simulators interfacing with the ATCSF via transcontinental land-line data links participated in the flight operations together with the computer-generated flights. One aircraft simulator (figure 3) was configured as a Convair 990 (CV-990), and the other (figure 4) as a Boeing 727 (B727). Both aircraft simulators were piloted by current airline pilots. The simulation facilities are discussed in appendix A.

GEOGRAPHICAL AREA. The area simulated was approximately a 150-nautical mile (nmi) radius of the Denver, Colorado, very high frequency omnidirectional range/tactical air navigation facility (VORTAC). The route and airway structure simulated for both arrival and departure flights was patterned after the Denver "four-corner post" system as of February 24, 1977 (figure 5). One runway, 26L, was used for all arrival traffic, while departures used runway 35R. The Denver Stapleton Airport runway layout is shown in figure 6, and the instrument landing system (ILS) procedure for runway 26L, as used in the simulation, is shown in (figure 7).

79-28-1

FIGURE 1. ATCSF CONTROLLER POSITIONS OF OPERATION

FIGURE 2. ATCSF PILOT COMPUTER KEYBOARD ENTRY OPERATING POSITIONS

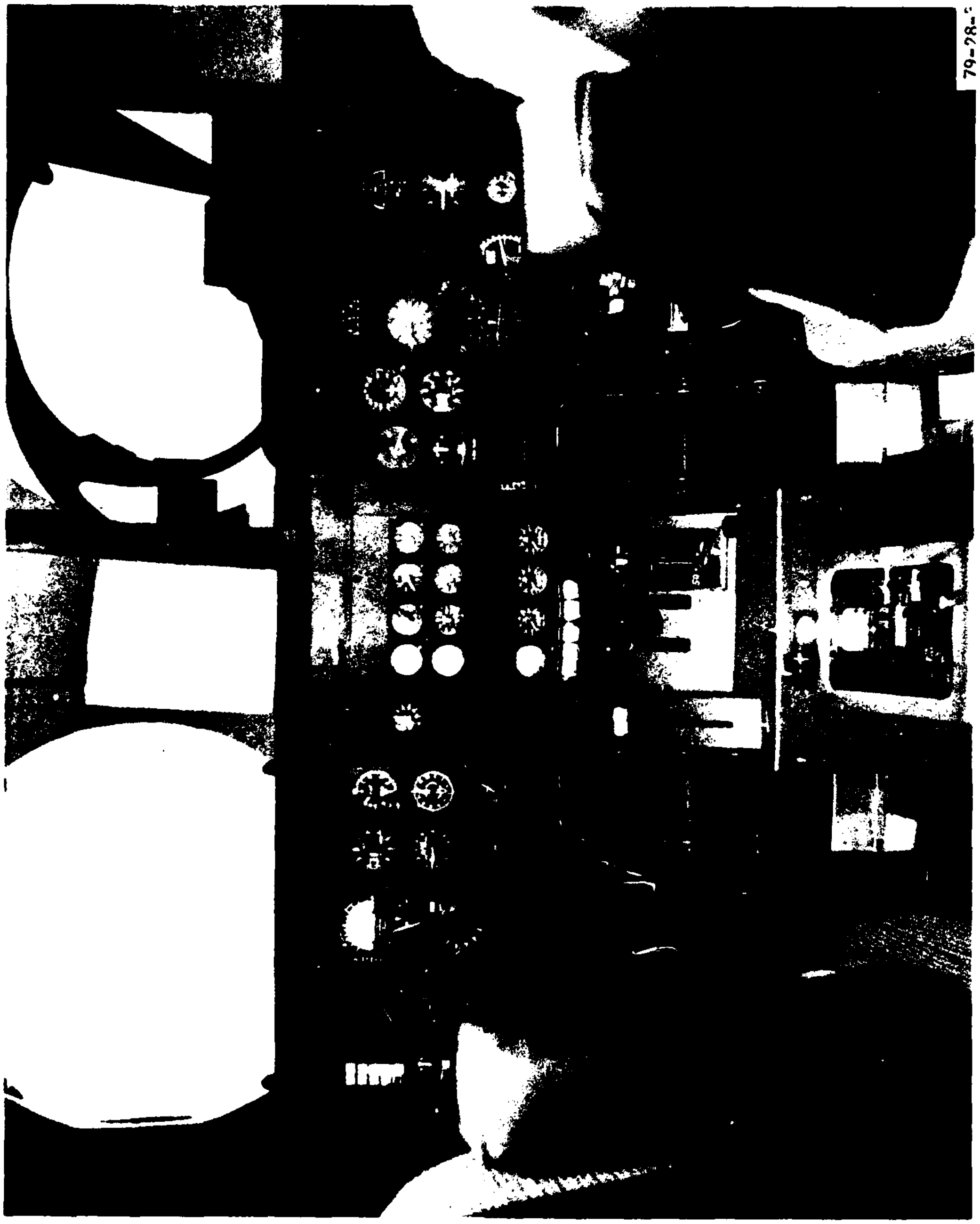

FIGURE 3. ARC CONVAIR 990 AIRCRAFT SIMULATOR

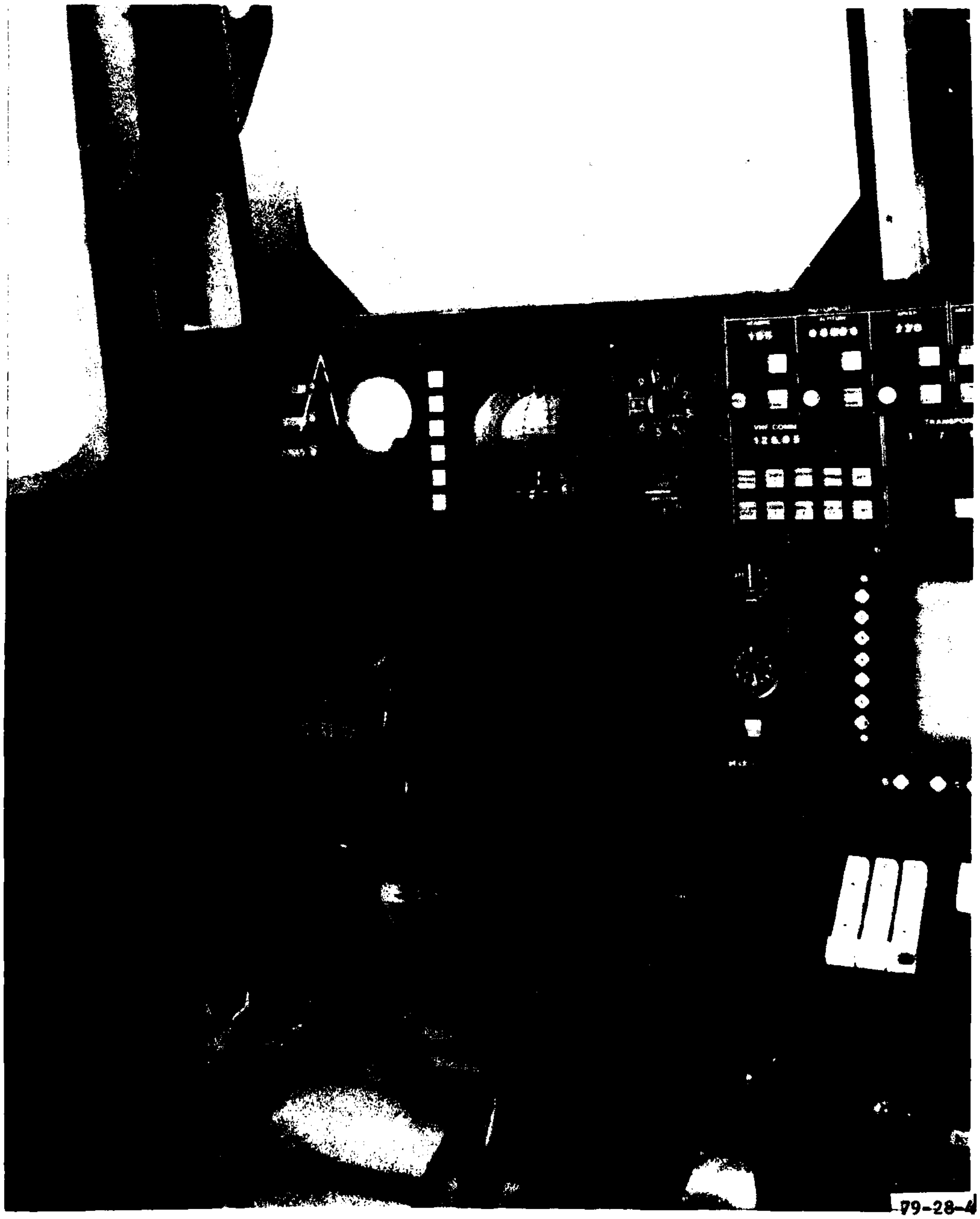

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FIGURE 4.   ARC BOEING 727 AIRCRAFT SIMULATOR

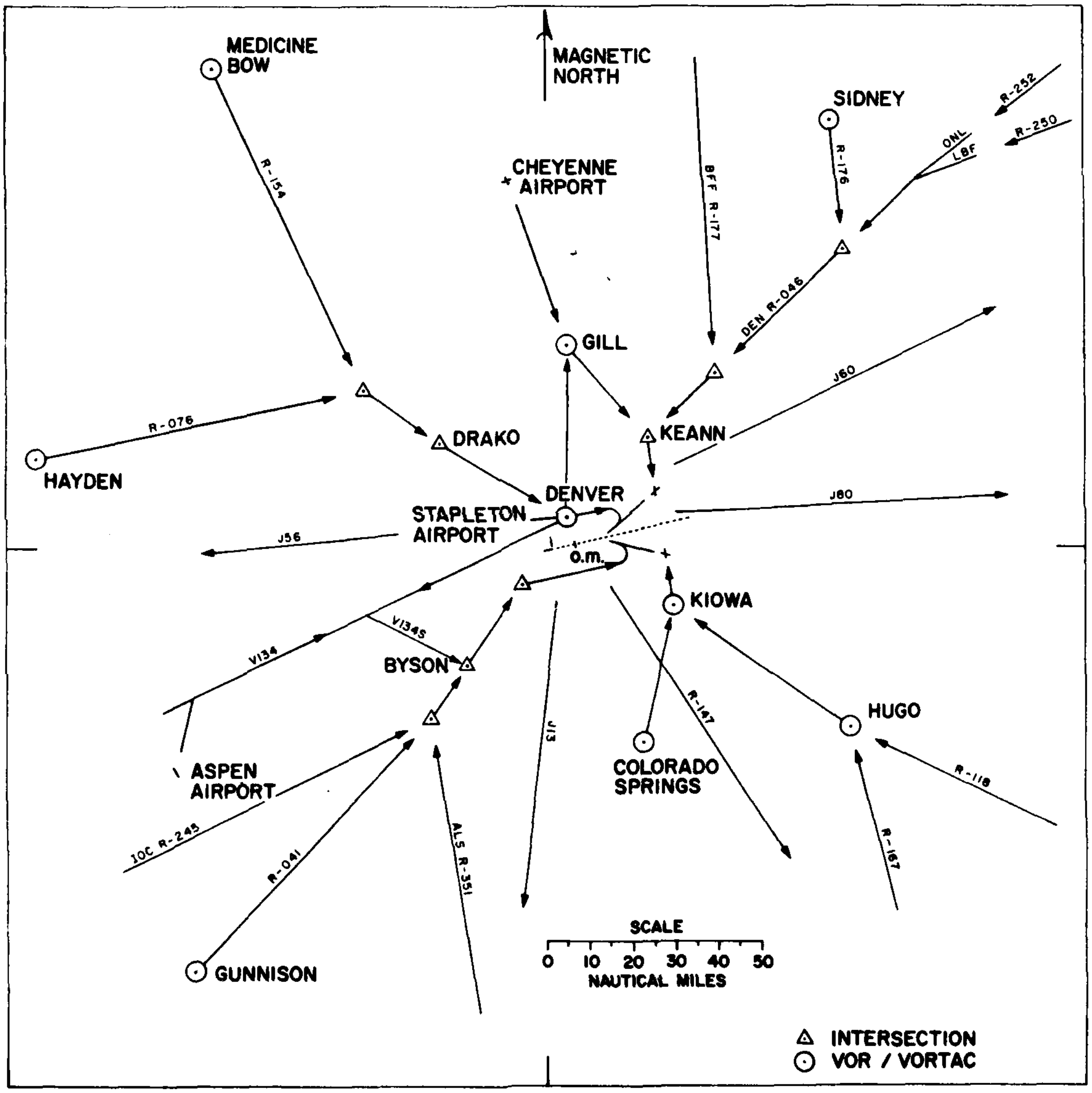


FIGURE 5. THE DENVER ROUTE AND AIRWAY STRUCTURE USED IN THE SIMULATION

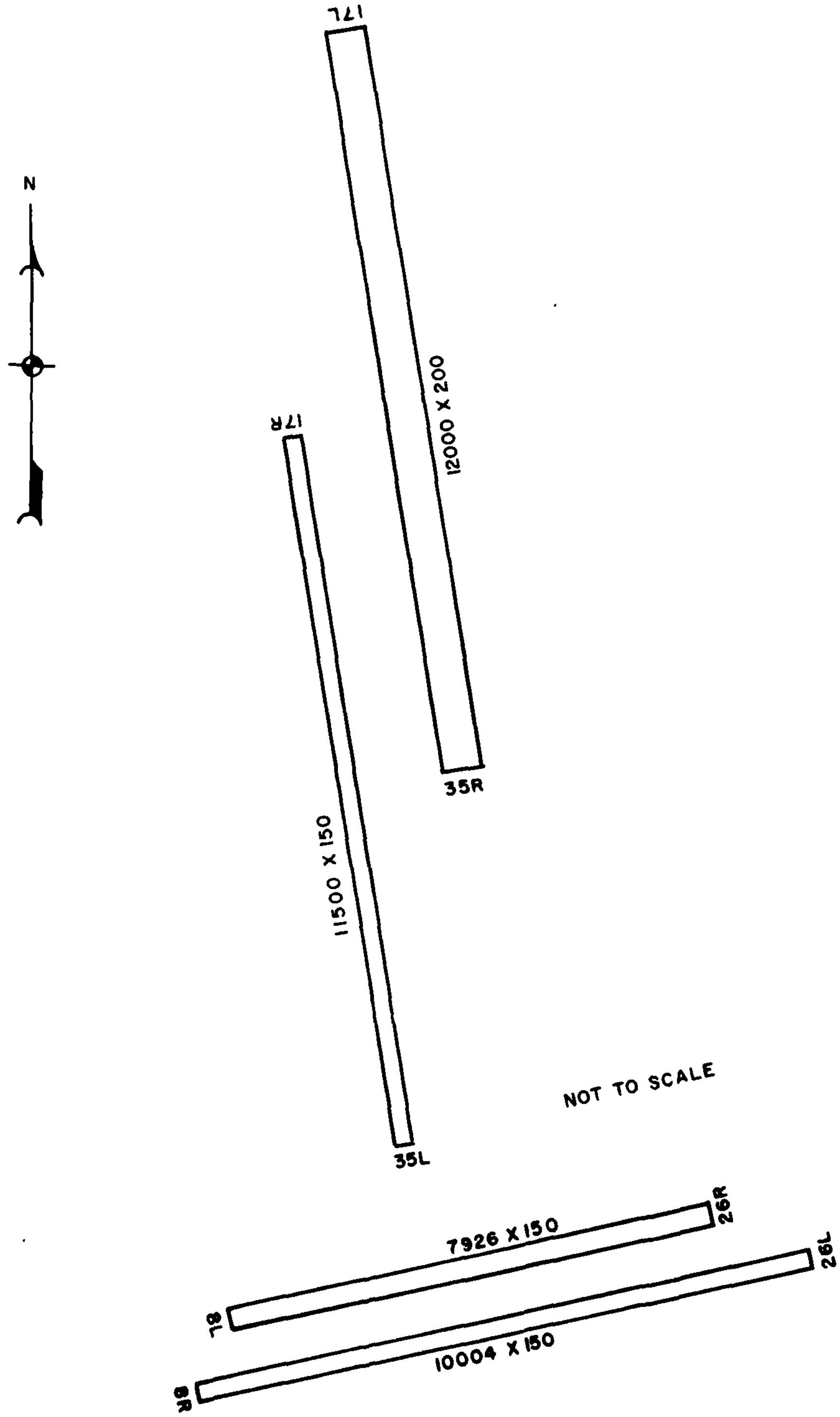
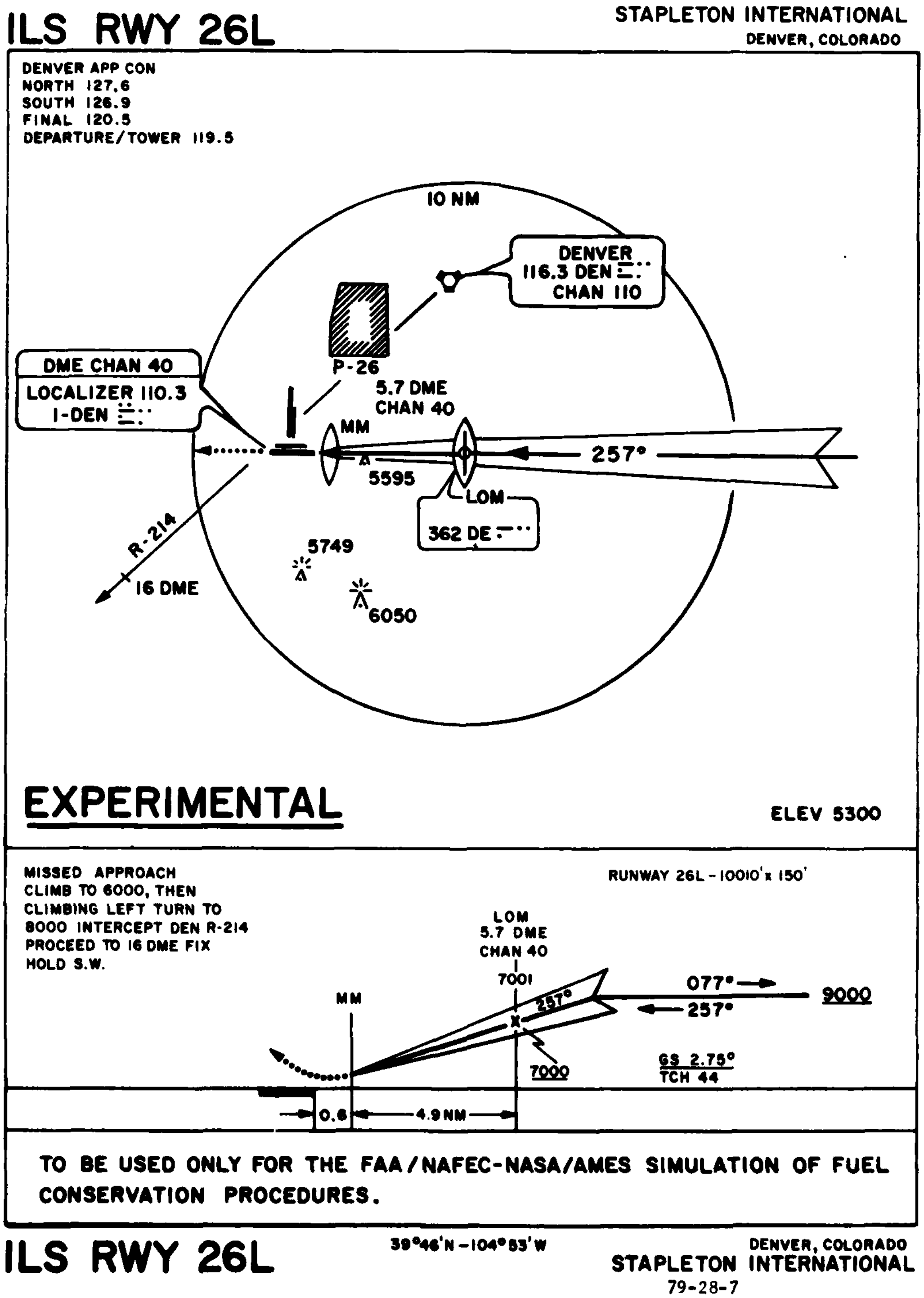


FIGURE 6. DENVER STAPLETON AIRPORT RUNWAY CONFIGURATION



79-28-7

FIGURE 7. THE ILS PROCEDURE FOR STAPLETON RUNWAY 26L AS USED IN THE SIMULATION

GENERAL ASSUMPTIONS. It was assumed that:

1. All arrival traffic would land on runway 26L. Weather conditions would be such that landings on 26R would be precluded. Independent departure operations would be conducted on runway 35R. Only Stapleton Airport traffic would be simulated because any satellite airport traffic would occupy "slots" in the Stapleton flow and be controlled by the same procedures.

2. The Denver Terminal Radar Approach Control (TRACON) would be the prime control facility, and the Denver Air Route Traffic Control Center (ARTCC) would be simulated only to the extent necessary to support TRACON activities. Problem-causing overtraffic and other unique situations could have been resolved by rerouting or other solutions.

3. Simulated wind conditions, surface and aloft, would not be used.

4. A system metering all arrival traffic would be required.

5. No fuel conservation procedures would be flown by aircraft cruising below flight level (FL)240. Since these procedures were designed for large transport type aircraft, they were not intended for light aircraft which use FL230 and below. The traffic below FL240 remained in the sample so that traffic interactions could be appraised.

FUEL CONSERVATION PROCEDURES. Two fuel conservative procedures were tested, profile descents and high-speed approaches.

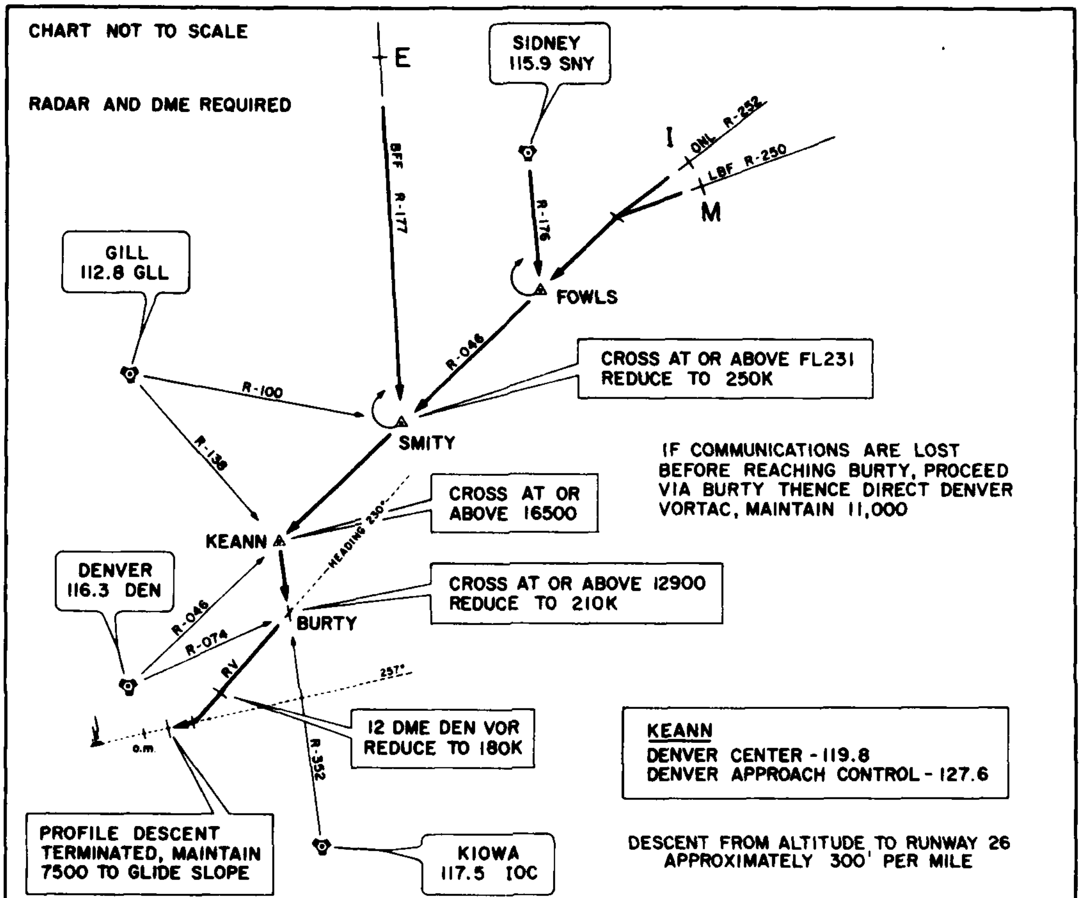
Profile Descents. A profile descent is defined as an unrestricted descent (except where level flight is required for speed adjustment; e.g., 250 knots at 10,000 feet mean sea level (m.s.l.)) from cruising altitude/flight level to interception of a glide slope or to a minimum altitude specified for the initial or intermediate segment of a nonprecision instrument approach (reference 1). Normally, the procedure is based on an altitude loss of 300 feet per nmi and terminates at the approach gate or where the glide slope or other appropriate minimum altitude is intercepted.

Essentially, the procedure applies the principle that turbojet aircraft should operate at as high an altitude as possible for as long as possible, preferably cruise, until the ideal distance from destination has been reached, then close the throttles, descend, and not use power again until the final approach has been reached.

For the simulation tests, the profile descent procedures were patterned after the Experimental Profile Descent Procedures published by the FAA for Denver Stapleton Airport in December 1976 (reference 2). Those experimental procedures were modified so that both azimuth and vertical guidance were provided to a point of alignment on the ILS final approach course below glide slope interception. By the design of the procedures, no ATC clearances were required other than the initial clearance to enter the profile from cruising level. Controllers monitored the progress of flights through the system and issued alternate clearances only as necessary for ATC purposes. Figures 8, 9, 10, and 11 show the procedure for each of the "four corners" of the Denver Stapleton Airport arrival flow patterns.

KEANN - RUNWAY 26 PROFILE DESCENT

STAPLETON INTL
DENVER, COLORADO



FROM OVER START POINT "E"

ALT	RADIAL	DME
410	BFF 177	45
390	BFF 177	51
370	BFF 177	57
350	BFF 177	63
330	BFF 177	69
310	BFF 177	75
290	BFF 177	81
280	BFF 177	84
270	BFF 177	87
260	BFF 177	90
250	BFF 177	93
240	BFF 177	96

FROM OVER SNY

ALT	RADIAL	DME
410	SNY 176	15
390	SNY 176	21
370	SNY 176	27
350	DEN 046	85
330	DEN 046	79
310	DEN 046	73
290	DEN 046	67
280	DEN 046	64
270	DEN 046	61
260	DEN 046	58
250	DEN 046	55
240	DEN 046	52

FROM OVER START POINTS "I" AND "M"

ALT	RADIAL	DME
410	DEN 046	103
390	DEN 046	97
370	DEN 046	91
350	DEN 046	85
330	DEN 046	79
310	DEN 046	73
290	DEN 046	67
280	DEN 046	64
270	DEN 046	61
260	DEN 046	58
250	DEN 046	55
240	DEN 046	52

EXPERIMENTAL
NOT FOR NAVIGATIONAL USE

KEANN - RUNWAY 26 PROFILE DESCENT

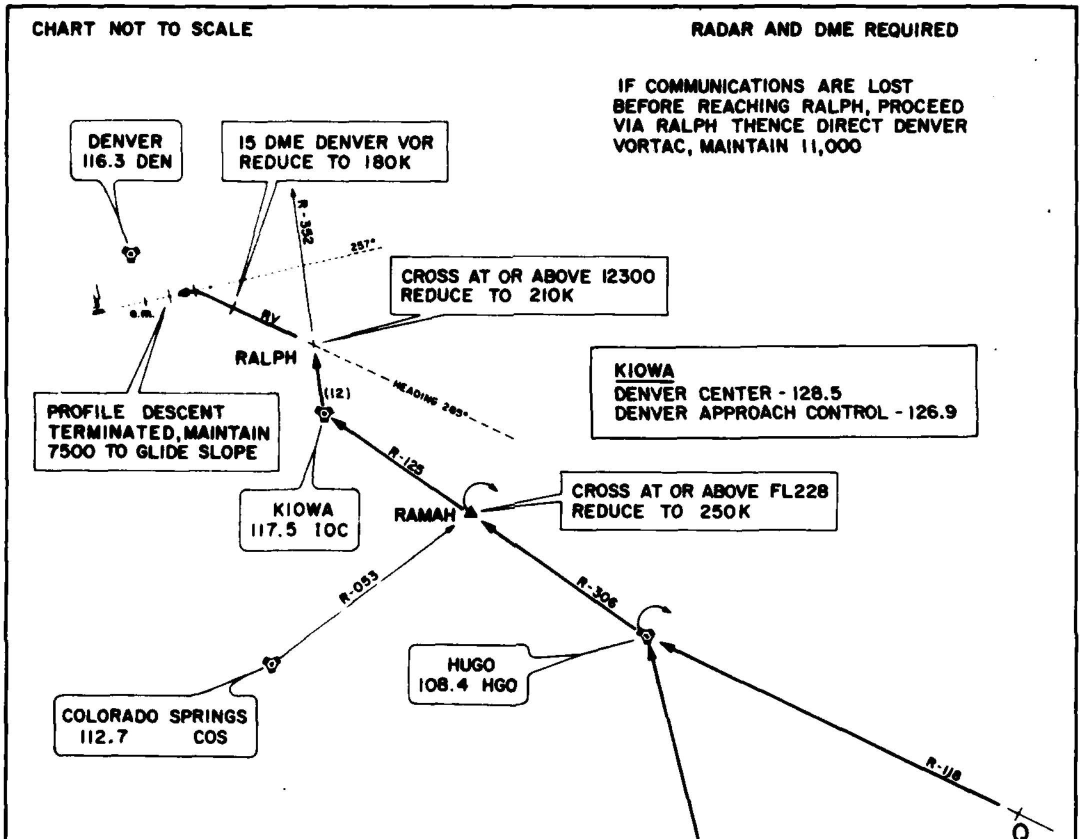
STAPLETON INTL
DENVER, COLORADO

79-28-8

FIGURE 8. SIMULATED PROFILE DESCENT PROCEDURE FOR THE KEANN CORNERPOST

KIOWA - RUNWAY 26 PROFILE DESCENT

STAPLETON INTL
DENVER, COLORADO



DESCENT FROM ALTITUDE TO RUNWAY 26
APPROXIMATELY 300' PER MILE

FROM OVER START POINT "Q"

ALT	RADIAL	DME
410	HGO 118	27
390	HGO 118	21
370	HGO 118	15
350	HGO 118	9
330	HGO 118	3
310	HGO 306	4
290	HGO 306	10
280	HGO 306	13
270	HGO 306	16
260	HGO 306	19
250	HGO 306	22
240	HGO 306	25

FROM OVER START POINT "U"

ALT	RADIAL	DME
410	HGO 167	27
39C	HGO 167	21
370	HGO 167	15
350	HGO 167	9
330	HGO 167	3
310	HGO 306	4
290	HGO 306	10
280	HGO 306	13
270	HGO 306	16
260	HGO 306	19
250	HGO 306	22
240	HGO 306	25

R-167
U

EXPERIMENTAL
NOT FOR NAVIGATIONAL USE

KIOWA - RUNWAY 26 PROFILE DESCENT

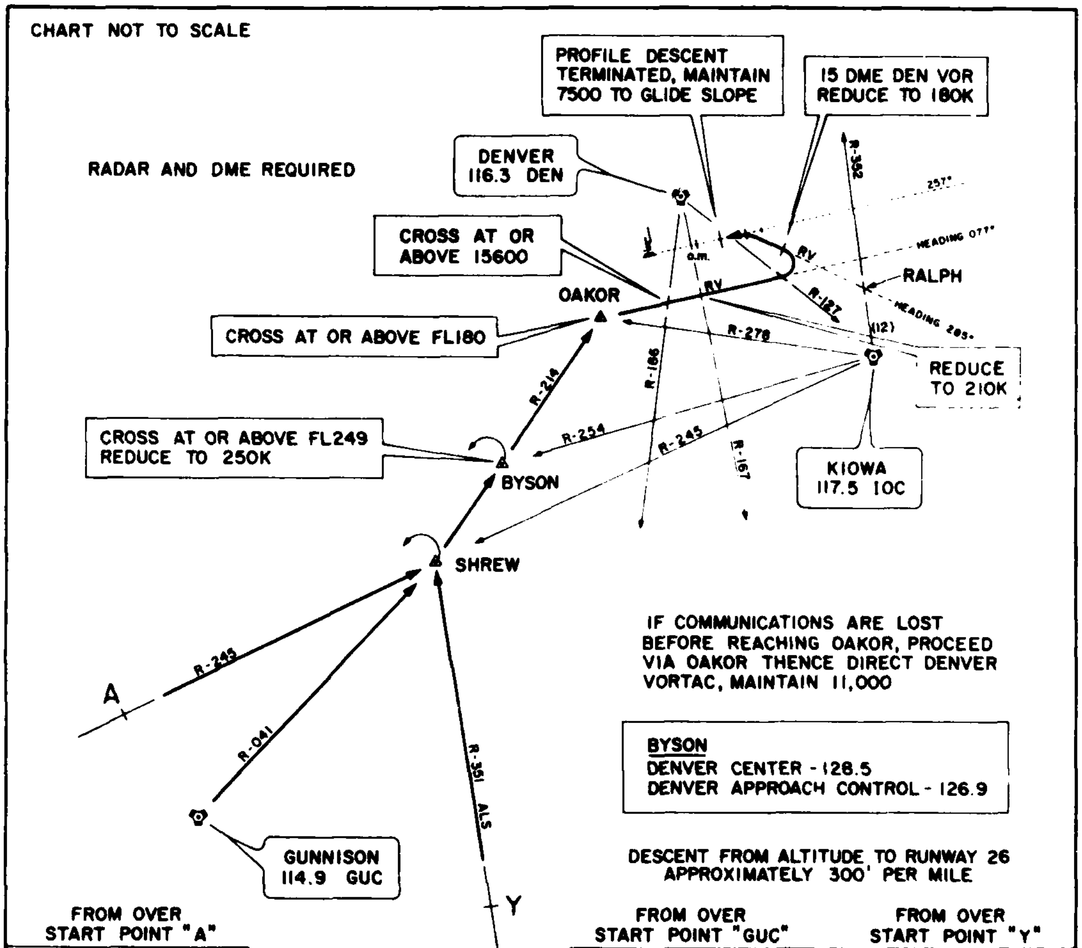
79-28-9

STAPLETON INTL
DENVER, COLORADO

FIGURE 9. SIMULATED PROFILE DESCENT PROCEDURE FOR THE KIOWA CORNERPOST

BYSON - RUNWAY 26 PROFILE DESCENT

STAPLETON INTL
DENVER, COLORADO



FROM OVER START POINT "A"

ALT	RADIAL	DME
410	IOC 245	95
390	IOC 245	89
370	IOC 245	83
350	IOC 245	77
330	IOC 245	71
310	IOC 245	66
290	DEN 214	54
280	DEN 214	50
270	DEN 214	47
260	DEN 214	44
250	DEN 214	41
240	DEN 214	38

EXPERIMENTAL
NOT FOR NAVIGATIONAL USE

FROM OVER START POINT "GUC"

ALT	RADIAL	DME
410	GUC 041	47
390	GUC 041	53
370	GUC 041	59
350	GUC 041	65
330	GUC 041	71
310	GUC 041	77
290	DEN 214	54
280	DEN 214	50
270	DEN 214	47
260	DEN 214	44
250	DEN 214	41
240	DEN 214	38

FROM OVER START POINT "Y"

ALT	RADIAL	DME
410	ALS 351	78
390	ALS 351	84
370	ALS 351	90
350	ALS 351	96
330	ALS 351	102
310	ALS 351	108
290	DEN 214	54
280	DEN 214	50
270	DEN 214	47
260	DEN 214	44
250	DEN 214	41
240	DEN 214	38

BYSON - RUNWAY 26 PROFILE DESCENT

STAPLETON INTL
DENVER, COLORADO

79-28-10

FIGURE 10. SIMULATED PROFILE DESCENT PROCEDURE FOR THE BYSON CORNERPOST

DRAKO - RUNWAY 26 PROFILE DESCENT

STAPLETON INTL
DENVER, COLORADO

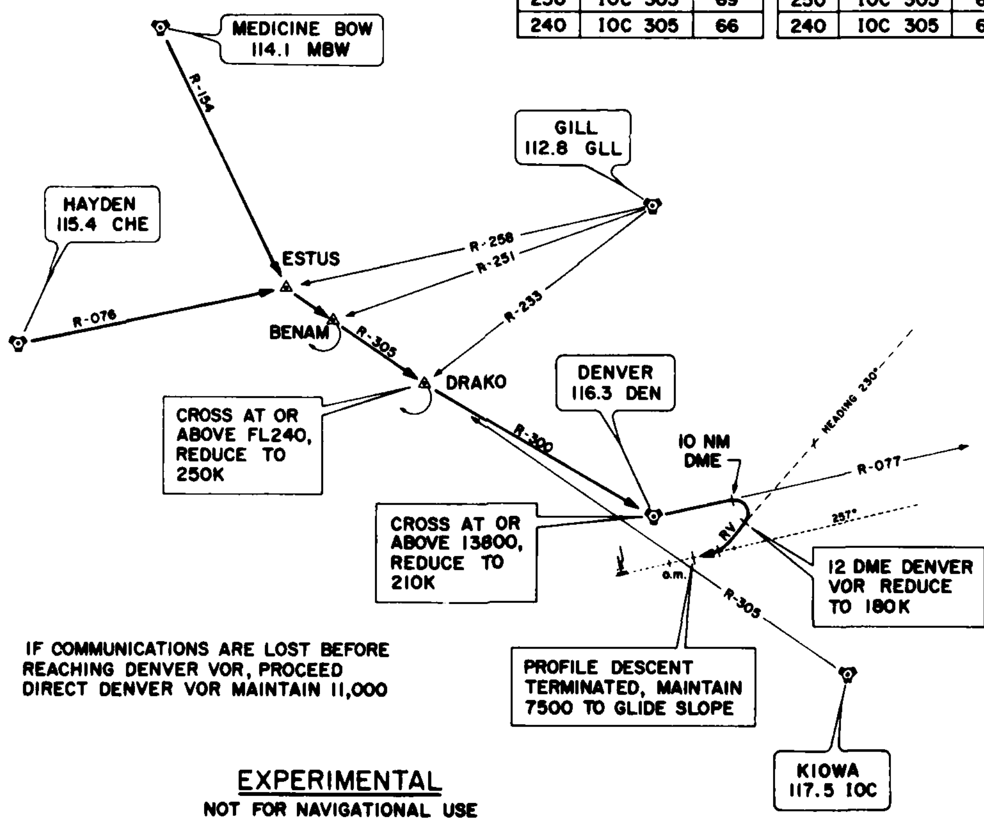
RADAR AND DME REQUIRED

CHART NOT TO SCALE

DESCENT FROM ALTITUDE TO RUNWAY 26
APPROXIMATELY 300' PER MILE

FROM OVER MBW			FROM OVER CHE		
ALT	RADIAL	DME	ALT	RADIAL	DME
410	MBW 154	51	410	CHE 076	47
390	MBW 154	57	390	CHE 076	53
370	MBW 154	63	370	CHE 076	59
350	MBW 154	69	350	CHE 076	65
330	MBW 154	75	330	CHE 076	71
310	IOC 305	87	310	IOC 305	87
290	IOC 305	81	290	IOC 305	81
280	IOC 305	78	280	IOC 305	78
270	IOC 305	75	270	IOC 305	75
260	IOC 305	72	260	IOC 305	72
250	IOC 305	69	250	IOC 305	69
240	IOC 305	66	240	IOC 305	66

DRAKO
DENVER CENTER - 119.8
DENVER APPROACH CONTROL - 127.6



IF COMMUNICATIONS ARE LOST BEFORE REACHING DENVER VOR, PROCEED DIRECT DENVER VOR MAINTAIN 11,000

EXPERIMENTAL
NOT FOR NAVIGATIONAL USE

DRAKO - RUNWAY 26 PROFILE DESCENT 79-28-11 DENVER, COLORADO STAPLETON INTL

FIGURE 11. SIMULATED PROFILE DESCENT PROCEDURE FOR THE DRAKO CORNERPOST

The procedures were provided in these formats for the pilots flying the ARC aircraft simulators. The illustrations show the detail of azimuth and altitude guidance information as well as required speeds throughout the descent from cruise level to the end of the profile at 7,500 feet m.s.l. The table on each chart provided the distance measuring equipment (DME) point where descent would ideally begin. That point would vary, since an aircraft cruising at a higher altitude would begin descent at a greater distance from destination than one cruising at a lower altitude. Upon determination of the ideal point by reference to the appropriate radial and cruise altitude in the table, the throttles were closed at that point, and descent was made at idle thrust. Power was not used again until the end of the profile when adjustments were made to complete the final approach and stabilize the aircraft for landing.

The profile for the descent of a given aircraft will depend on type and weight, but the rate of descent used as a standard for simulation was approximately 300 feet per nmi for both the piloted aircraft simulators and the ATCSF computer-generated flights. Whereas, the manned aircraft simulators were piloted in the execution of the profile descent procedure, the computer-generated flights were software programed for automatic execution of the same procedures.

Figure 12 is a crossview of a typical profile descent procedure as it was simulated. The figure illustrates a flight cruising at FL 350. Descent began approximately 100 nmi from touchdown on runway 26L. Transition from mach to indicated airspeed (IAS) was made, and the airspeed was reduced to 250 knots at approximately 60 nmi and FL240. Speed was gradually dissipated and reduced to 210 knots at about 20 nmi between 14,000 and 13,000 feet.

Not shown in the illustration, because it was not used when the high-speed approach procedures were executed, is the final speed reduction to 180 knots between 13 and 14 nmi from touchdown and prior to interception of the ILS.

High-Speed Approaches. The two high-speed final approach procedures simulated were the delayed flap and the IATA. The delayed flap procedure was developed by NASA and the IATA procedure by the International Air Transport Association.

The delayed flap approach was developed utilizing an onboard computer to effect a low-noise, fuel-conservative alternative to the conventional jet transport instrument landing approach procedure (reference 3). In contrast to conventional approaches, which are flown at constant airspeeds of 140 to 160 knots, depending on aircraft type and weight and high landing flap settings throughout, the delayed flap approach begins in a clean configuration at a high initial speed between 240 and 210 knots. An altitude of 3,000 feet above ground is maintained to ILS glidepath interception at about 10 nmi from touchdown. The pilot begins descent on the glidepath, retards the throttles to idle, and the aircraft begins slowly to decelerate. About 6 nmi from touchdown, the pilot is given a cue from an onboard computer to lower gear and later the approach flaps. The final adjustment of flaps to the landing position is made

at about 4 nmi. The aircraft decelerates to final approach speed at an altitude of 500 feet, 1.5 nmi from touchdown. At this point, the pilot advances the throttles to approach power, and the remaining portion of the approach is flown at a stablized airspeed similar to conventional approach.

The IATA approach (reference 4) requires no onboard computer. The approach speeds are higher than a conventional approach but less than the speeds used in the delayed flap approach. IATA approach procedure is such that at a distance of 12 to 15 nmi, the aircraft is in level flight at 3,000 feet above ground at a speed of 210 knots and in a position to intercept the ILS. Prior to glide slope interception, the aircraft decelerates to reach 185 knots at the point of glide slope intercept. Established on the glide slope, the aircraft is decelerated to final approach speed plus 20 knots by the time an altitude of 1,500 feet is reached. A further speed reduction is then made so that final approach speed is reached at 1,000 feet. Power adjustments are then made, and the remainder of the approach to touchdown is made in the conventional manner.

The two procedures are similar in that both employ a technique which comprises a decelerating process employing delays and/or reductions in the application of drag and the use of flaps, with a consequent reduction in the amount of power required to conduct the approach. The difference between the two approaches is that the delayed flap approach requires the use of an onboard computer system to determine the timing for flight configuration changes involving induced drag and speed adjustments. The timing for these changes in the IATA approach are made manually by pilot reference to DME fixes or controller advisories with respect to the position of the aircraft and a known fix on the controller's display.

Figure 13 shows speed profiles and respective distances to touchdown for delayed flap, IATA, and conventional approaches. Flight time required from the 18-nmi point to touchdown, as calibrated for a B-727 aircraft for the different approaches, is shown to the lower right in the figure.

As with the profile descent procedure, the piloted flight simulators were flown in accordance with the procedures specified for the high-speed approaches, but those procedures could not be positively duplicated in the NAFEC simulation laboratory within the time alloted for software preparation. It was recognized that the elapsed time difference between the various approaches was a prime factor, and the procedures for the computer-generated flights were designed so that approach speeds and time differences between the approaches remained reasonably realistic.

Simulated Approaches/Descents. Computer-generated flights that simulated delayed flap approaches maintained 210 knots to a point 4.5 nmi from touchdown. At that point, a reduction to final approach speed automatically began, and final speed was attained about 1.5 nmi from touchdown. Flights that simulated IATA approaches maintained 210 knots to a point 13 nmi from touchdown. At that point, controllers issued clearances for speed reductions to

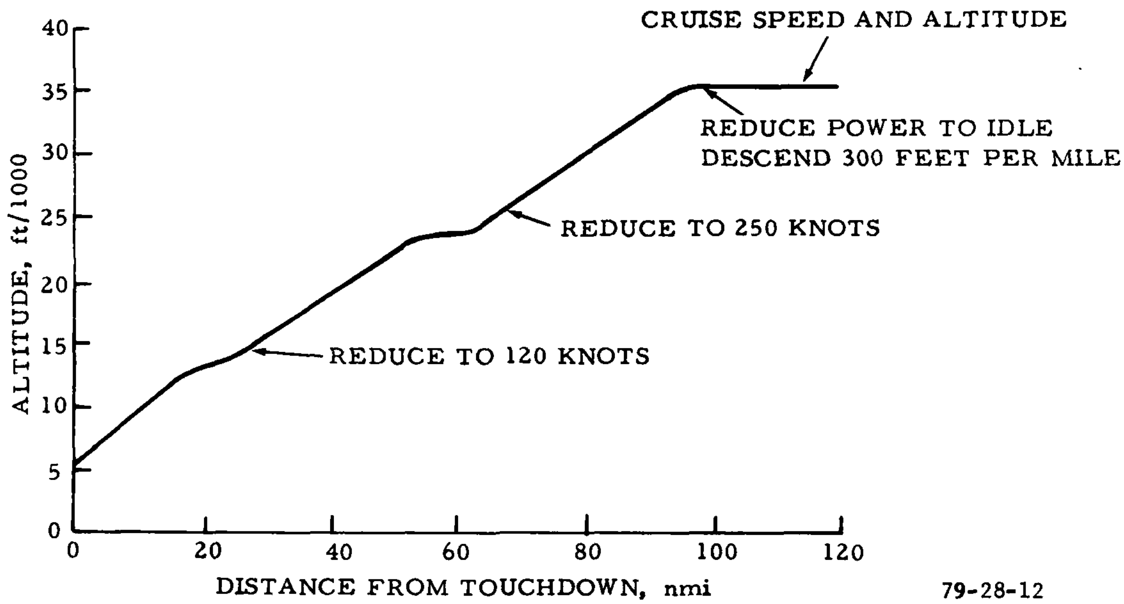


FIGURE 12. CROSSVIEW OF A TYPICAL PROFILE DESCENT PROCEDURE AS SIMULATED

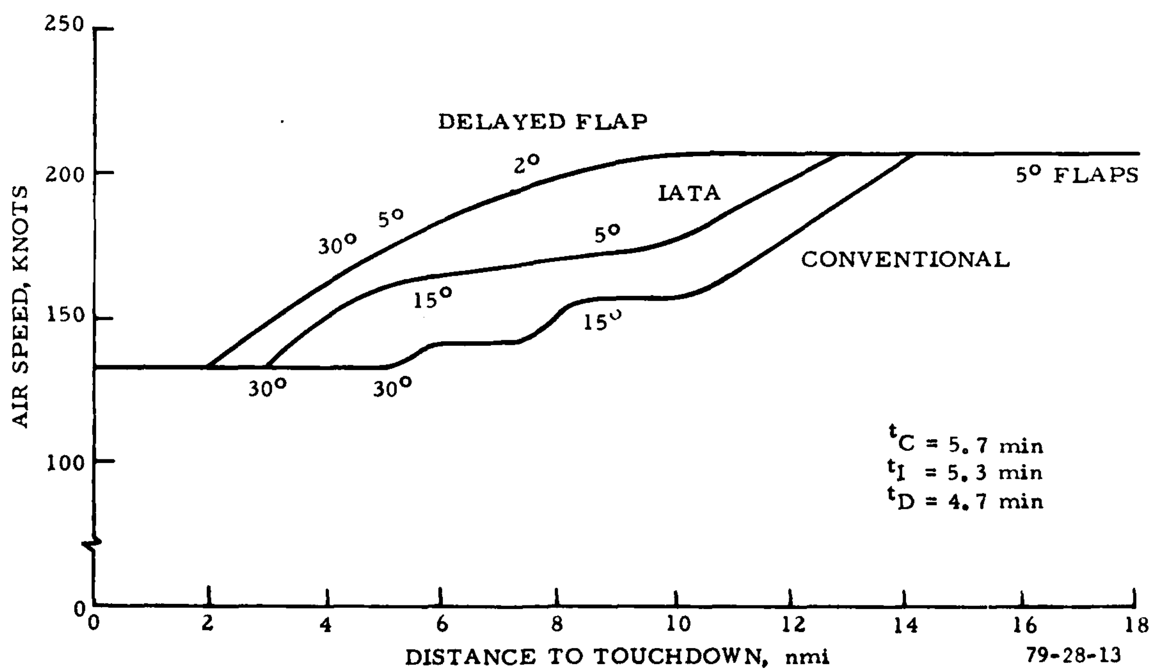


FIGURE 13. SPEED PROFILES FOR DELAYED FLAP, IATA, AND CONVENTIONAL APPROACHES

180 knots. A speed of 180 knots was then maintained to the 4.5-nmi point where the reduction to final approach speed automatically began as with the delayed flap approach flights.

Computer-generated flights that simulated the testing of the profile descent followed by an IATA high-speed approach in the same flight could not complete both procedures. Because of software limitations, when the computer entry for the 13-nmi ATC speed reduction clearance was made, the profile descent was interrupted. The result was that, using IATA approach, profile descents could not be completed.

TRAFFIC SAMPLE. The traffic sample was developed from an analysis of a Denver "busy day" in January 1977. The traffic was categorized by aircraft types, routes, and numbers of flights. The results of this analysis were duplicated for simulation except that the number of flights was increased by 20 percent. That resulted in a traffic sample input rate of 53 arrival flights per hour. Thirteen, or about 25 percent, of those flights were low-performance aircraft. Representative departure flights were programed by the NAFEC project team in accordance with the same parameters as the arrivals.

ATC FACILITIES AND CONTROL PROCEDURES. The Denver TRACON was simulated as closely as possible, and the ARTCC was simulated only in part as necessary to support the tests.

Four Denver TRACON control positions were simulated: North Arrival, South Arrival, Final, and Departure. An additional, nonradar position performed the metering/flow control for arrival traffic. (This position was considered to be within the ARTCC, but the function served both the ARTCC and the TRACON.)

Two positions were operated to perform the necessary functions of the Denver ARTCC. A true representation of the facility's sectorization adjacent to the terminal area was neither intended nor necessary.

Control procedures used were in accordance with those set forth in the Air Traffic Control Handbook (reference 5). Specific details concerning ATC operating positions and procedures simulated are presented in appendix B.

METERING OF ARRIVAL TRAFFIC. All arrival traffic under all conditions were metered into the system at peripheral points in accordance with a metering model developed for the simulation by Computer Sciences Corporation under contract to the FAA. The model sequenced the traffic on a basis of "first-come, first-serve" according to a projected touchdown time for each aircraft.

The intrail spacing requirements for the different aircraft weight classes and the compression factor caused by different approach speeds were both considered in the model design. A description of the metering model is provided in appendix C.

TEST DESIGN.

Four different in-flight arrival "conditions" were simulated, and data were collected for comparisons between conditions and procedures within conditions. For the remainder of this report, they will be referred to as condition 1, 2, 3, and 4.

CONDITION 1. No fuel conservation procedures were used. All arrival flights navigated by conventional present-day methods using very high frequency omnidirectional range (VOR) route structures and radar vectors from ATC. Altitude and speed control clearances were given by ATC in the usual manner. Data collected under this condition were used as a baseline for comparison with the other conditions.

CONDITION 2. Profile descent procedures were used. All arrival flights cruising FL240 and above conformed with the procedure.

CONDITION 3. Delayed flap and IATA high-speed approach procedures were used. Since the profile descent procedure was not used, arrival flights cruising FL240 and above conformed with conventional procedures during the descent and executed the high-speed procedures on the approach. The number of aircraft flying those procedures was divided equally; that is, 50 percent of the total number of aircraft were scheduled to conform with the delayed flap procedure and 50 percent with the IATA.

CONDITION 4. This condition combined the use of both the profile descent and the high-speed approach procedures during a single flight. As in condition 3, the number of aircraft making each type of high-speed approach was divided equally.

TEST MATRIX. The simulation was planned to provide statistical results between each of the four test procedures. From a team of controllers, four were selected to operate the test control position (final control). The four controllers were randomly assigned to the test position for two consecutive runs under each condition. The test matrix is shown in table 1.

In addition to the 32 test-design data collection runs shown in table 1, eight additional runs were conducted to collect data when aircraft were not required to maintain a speed of 250 knots IAS or less at and below 10,000 feet m.s.l. in the terminal area. For the eight additional runs, data were collected on selected departure flights flying two separate departure procedures. The subject aircraft were all B-727's, and all flew the same standard instrument departure route.

Under one procedure, the aircraft were required to maintain 10,000 feet m.s.l. or below and 250 knots or less while in the terminal area. (That represented an in-flight distance of between 25 to 30 nmi). Under the other procedure, the same aircraft were allowed to fly at the best performance speed, and climbs were not restricted except as occasionally necessary for ATC purposes.

TABLE 1. TEST MATRIX BY CONDITION AND NUMBER OF RUNS*

High-Speed Approach** Procedures	Profile Descent Procedures***	
	Without	With
Without	Condition 1 8 runs	Condition 2 8 runs
With	Condition 3 8 runs	Condition 4 8 runs
Total runs	16	16 = 32

* Two replicates for each of the four controllers for each condition.

** Delayed flap or IATA high-speed approach procedures flown by aircraft cruising FL240 and above. The number of aircraft flying each procedure was divided equally.

*** Flown by aircraft cruising FL240 and above.

Those eight runs were made without using the metering model for arrival flights, and metering was done manually by the controllers. Measurements were compared to detect any possible differences between the two metering procedures.

MEASUREMENTS. From the data recorded, the measures were reduced and analyzed to determine benefits between and within the test conditions. The measures apply only to the results of entire flights; i.e., aircraft that entered and landed during the 1.5-hour data collection period. A test run was 1 hour and 45 minutes. The arrival rate measure accounted for all aircraft that landed in the data period regardless of the start time.

Measurements were tabulated by test condition, altitude strata, direction of flight by quadrant, aircraft fuel category with attendant statistical results. Aircraft entering the simulated area at cruising altitudes of FL240 and above were capable of flying the fuel-conservation procedures. Those at FL230 and below could not fly the fuel procedures, therefore, altitude strata, FL240 and above/FL230 and below, defined procedural and nonprocedural aircraft.

Measures for fuel conservation procedures (conditions 2, 3, and 4) are divided into two groups; complete and incomplete, with associated scores for both parts. As the name indicates, "complete" means aircraft which completed the procedure, and "incomplete" means that the procedure was interrupted prior to completion. The incomplete procedure is further divided into total "before" and total "after". The "before" identifies that portion of the procedures which was completed, and the "after" identifies the "off-procedure" portion of

the flight when the aircraft was in conventional flight. The measures were:

1. Number of Aircraft: The total number of test aircraft that completed a flight from start point to runway during the data collection period.

2. Fuel: The average amount of fuel consumed, in pounds, per completed flight. (A gallon of jet fuel weighs approximately 6.7 pounds and aviation gas weighs 6.0 pounds per gallon.)

3. Distance: The average distance flown per aircraft, in nmi, from the start point to landing.

4. Time: The average flight time per aircraft, in seconds, from start point to landing. (Time does not include delay.)

5. Workload: The average number of control clearances issued by the controller per aircraft. The clearances are of three types: vectors (heading changes), altitude changes, and speed changes. Dividing the number of clearances issued to entire flights by the number of entire flights gives the average by type of clearance per aircraft. Summing the averages of the clearance types gives the total number of average clearances per aircraft from first contact to landing.

6. Interrupted Procedure Altitude: The average altitude at which the aircraft left the procedure being tested. During the profile descent, the altitude was determined by a heading change, altitude change, or speed change (or a combination thereof) other than specified by the procedure. Altitudes for IATA or delayed flap approaches were determined by a speed change that resulted in a speed lower than specified in the procedure. There was no interrupted procedure altitude for condition 1 because aircraft were not required to fly specific procedures as conditions 2, 3, and 4.

7. Arrival Rate: The average number of aircraft that landed per hour during the data period per run. Since the data period was 1.5 hours, the hourly rate was obtained by dividing the number of landed aircraft by the data time.

8. Number of Delayed Aircraft: The total number of completed flights that were delayed for each test condition.

9. Delay: The time difference, in seconds, between the scheduled start time and the actual start time for completed flights.

STATISTICAL METHOD.

To determine significant differences between the test conditions; i.e., conventional, profile descent, and high-speed approach procedures, the data were subjected to the Analysis of Variance (ANOVA) (reference 6) and Newman-Keuls Multiple Comparison Tests (reference 7).

A one-way analysis of variance design was used on the experimental data to find meaningful results from the data; i.e., statistically significant differences among the treatment group means. To further analyze the data, the Newman-Keuls multiple comparisons tests were used. This method tells more about "why" treatment groups in a one-way ANOVA are significant. The Newman-Keuls test is an offshoot of the Studentized Range test.

The significance level was preestablished at $\alpha = 0.05$. The null hypothesis for these tests was that the means of the various treatments were equal. If the means were found to be not statistically different, rejection of the null hypothesis would occur less than 5 percent of the time. Differences found to be nonsignificant indicate that the means are considered equal.

A matrix of statistical test conditions and subconditions is given in table 2. The averages of the test conditions were analyzed first by comparison of the four conditions summary averages followed by a test within each condition that had more than one treatment; for example: condition 2, profile descent complete versus profile descent incomplete; condition 3, IATA versus delayed flap, complete and incomplete; condition 4, profile descent, complete and incomplete, with delayed flap complete and incomplete and IATA complete and incomplete. (Due to simulation limitations and programing time, it was not possible for the aircraft to complete a profile descent combined with either a complete or incomplete IATA approach.)

The purpose of the test runs was to determine by statistical evaluation which condition procedure obtained the best score under each measure. To answer the question; "Do profile descent and/or high-speed approach procedures save fuel, reduce workload, save flight time, and distance?" the data are analyzed first for the differences <u>between</u> conditions and then for differences <u>within</u> each condition. (Condition 1, conventional procedures, has no analysis <u>within</u> the condition. This condition was used as base data.)

Data tables and summary tables are presented in appendix D. Under each summary table for each condition are the statistical results for each measure by altitude strata. The significant differences are shown by paired numbers for each measure. Nonsignificant differences are not shown. Tables which follow the summary table for each condition give the breakdown by direction of aircraft entry and aircraft fuel category for each measure. These data made up the summary table for each condition.

STATISTICAL RESULTS

GENERAL.

The results are broken down into two parts. First the statistical differences are given for <u>between</u> condition comparisons; i.e., how the measures in one condition compare to similar measures in other conditions. Second, the statistical differences <u>within</u> each condition are shown; i.e., subcondition elements such as complete versus incomplete or delay flap versus IATA procedures. The results are given as a strictly objective comparision without

TABLE 2. MATRIX OF STATISTICAL TEST CONDITIONS AND SUBCONDITIONS

Systems Measures	Cond. 1 Baseline Data	Cond. 2 Profile Descent		Cond. 3 High-Speed Approaches				Condition 4: Combined Profile Descent High-Speed Approaches					
								Profile Descent					
								Complete		Incomplete			
				DF		IATA		DF		DF		IATA	
		Comp.	Inc.	Comp.	Inc.	Comp.	Inc.	Comp.	Inc.	Comp.	Inc.	Comp.	Inc.
No. Aircraft	x	x	x	x	x	x	x	x	x	x	x	x	x
Fuel	x	x	x	x	x	x	x	x	x	x	x	x	x
Distance	x	x	x	x	x	x	x	x	x	x	x	x	x
Time	x	x	x	x	x	x	x	x	x	x	x	x	x
Workload	x	x	x	x	x	x	x	x	x	x	x	x	x

subjective purview. However, both the between and within results are then further expanded and amplified in the ANALYSIS section, where trends and observations are also discussed.

STATISTICAL RESULTS BETWEEN CONDITIONS.

Listed in table D-1 are the total number or mean scores for each measure by direction and condition, with the system total or mean scores of the eight test runs for each test condition. The Newman/Keuls statistical analysis was conducted on the system scores. The resultant statistical significant differences (paired numbers) are shown for each measure by altitude strata scores. Except for workload, no cross analysis was made between the altitude strata scores, due to the fact that the types of aircraft are different above and below 240.

NUMBER OF AIRCRAFT. There was no significant difference in the total number of flights between conditions by altitude strata.

FUEL SAVINGS. For aircraft that operated in the FL240-and-above strata, there was a significant fuel saving for profile descent (condition 2) aircraft compared to the other conditions. There was no significant difference in the amount of fuel used between conventional (condition 1) and high-speed approaches (condition 3). (The fuel data for combined profile descent/high-speed approach (condition 4) was found to be inconsistent and is not included in this report.)

For aircraft that operated in the FL230-and-below strata, the only significant difference in fuel burned was between profile descent (condition 2) and high-speed approaches (condition 3) where the lesser amount used was found in condition 3. It should be remembered that the primarily light-weight aircraft at FL230 and below did not use the procedures themselves but were impacted by the large commercial descending aircraft that were using the procedures.

DISTANCE. The distances flown by aircraft in the FL240-and-above strata were significantly less for conventional and high-speed approaches (condition 3) when compared to profile descent (condition 2). There was no significant difference found between conditions 1, 3, and 4, and no difference between conditions 4 and any of the other conditions. There were no significant differences between distances flown in any of the conditions by aircraft operating in the FL230-and-below strata.

TIME. Flight time was significantly less in condition 4 than in conditions 1 and 2 for aircraft in the FL240-and-above strata. In the strata of FL230 and below, the flight time was significantly greater in condition 2 than conditions 1 and 3.

WORKLOAD. Controller workload was found to be significantly less in conditions 2 and 4 than 1 and 3 for aircraft in the FL240-and-above strata. Each of the fuel conservative procedures resulted in less ($\alpha = 0.05$) controller workload than conventional procedures. Table 7 shows that reductions of 38 percent were found with profile descents, 14 percent with high-speed approaches, and 39 percent with profile descent and high-speed approaches combined. Even though there was a workload reduction with the high-speed approaches, there

was less efficiency in that respect than with either profile descents or with the profile descent and high-speed approach combination. The latter two procedures showed 27 and 29 percent less workload, respectively, than the high-speed approaches.

Although there were differences in all three of the workload measures, the differences were mainly found in the number of radar vectors and speed control clearances (appendix D). As expected, the greatest reductions were found when the profile descent procedures were used, because the profile descent procedures provided the pilot with both azimuth and altitude guidance information with no requirement for ATC clearances. The workload reduction with the high-speed approach procedures was also because of the procedural difference. Aircraft that flew high-speed approach procedures, in general, required one less speed control clearance than aircraft flying conventional procedures. Data comparison showed that the difference was an average of 0.9, or about 14 percent per aircraft. Greater workload was involved in controlling IATA approach flights than delayed flaps.

Workload in controlling aircraft in the FL230-and-below strata was significantly greater in condition 4 than in conditions 1 and 3. There was no significant difference between conditions 1, 2, and 3.

ARRIVAL RATES. Table D-2 shows the arrival rates by direction and test condition for both altitude strata. Statistical tests resulted in no significant differences between the test conditions for both altitude strata. The differences in rates by entry direction (quadrant) were not tested for significance. The obviously higher rates attained from the northeast and southwest quadrants resulted because the balance of input traffic sample data favored those two quadrants.

DELAY. Tables D-3 and D-4 show the number of aircraft that were delayed and the amount of time each flight was delayed. These data are presented by quadrant of flight and test condition for both the FL240-and-above and FL230-and-below altitude strata.

Table D-3 shows that the number of delayed aircraft in both altitude strata was consistent between the several test condiitons. There were no significant differences in either strata. It is interesting to note, in a comparison of delay with arrival operations rates in table D-2, that the number of aircraft delayed per hour consistently exceeded the hourly operations rates.

Table D-4 shows that the amount of delay time was consistently ($\alpha = 0.05$) higher in conditions 3 and 4 than in conditions 1 and 2 in both altitude strata and in the system averages. There were no significant differences between conditions 1 and 2 or conditions 3 and 4.

Within the system averages, delays ranged from 517 seconds in condition 1 to 761 seconds in condition 4. Although delays were about the same for aircraft in both altitude strata in condition 1, the per-aircraft delay in the lower strata was progressively increased across the several test conditions at a greater rate than in the higher strata. Delays in the lower strata were nearly the same in conditions 3 and 4, but were about 2 minutes longer in condition 4 than flights in the higher altitude strata.

Although no statistically significant tests were conducted within the direction quadrants or across quadrants and/or test conditions, it is noteworthy that the traffic from the southwest in the FL240-and-above strata consistently received less delay than the other three quadrants. Similarly, the greatest amount of delay incurred by low-performance aircraft in the FL230-and-below strata was in traffic from the northwest.

STATISTICAL RESULTS WITHIN CONDITIONS.

GENERAL. The purpose of comparing results within each condition is to show differences between subcondition treatments. The complexities of the analysis increase with the number of subcondition treatments. This is particularly obvious in condition 4 which has six treatments (table 2): profile descent, LATA, and delayed flap in combination with complete and incomplete procedures. The analysis of each condition is shown in the condition summary tables (appendix D).

Comparisons of aircraft measures for both altitude strata are given only for workload. Comparison of the other measures was not possible, since there was no commonality of routes or number and type of aircraft.

Associated with each condition are the measure tables in appendix D. These tables give the average scores by entry direction and aircraft category for each altitude strata. Except for condition 1, the tables also accounted for complete and incomplete procedure results for conditions 2, 3, and 4.

The statistical analysis results are shown for each condition by paired numbers for each measure. No analysis was made for differences between entry direction (feeder quadrant) and category. The five aircraft fuel categories and four feeder quadrants data are included, but no analysis or comparisons were made.

CONDITION 1. The purpose of condition 1 test runs was to obtain basic measure scores on present-day conventional descent and approach procedures with the common traffic sample used in all conditions tested. The summary of measurement averages is listed in table D-5. Tables D-6 to D-10 list the detailed average scores for each measure by direction and fuel category. It was found that workload was significantly greater for aircraft FL240 and above compared to aircraft FL230 and below.

CONDITION 2. The summary of mean scores for profile descent is listed in table D-11 with statistical results listed for each measure. The mean scores were obtained from tables D-12 to D-17. The only treatment effects on system measures within this condition were the effects of complete and incomplete profile descents.

Number of Aircraft (Table D-12). The number of aircraft that completed the profile descent procedure was significantly less than when the procedure was incomplete. Since the lower speed aircraft operating in that FL230-and-below strata were making approaches to the same runway as the profile descent aircraft from FL240 and above, the speed differences between the

two often required controllers to interrupt the profile descent procedure for separation purposes. Generally, the interruption occurred approximately 20 nmi from the runway, based on an average interrupted procedure altitude of 13,252 feet m.s.l., (table D-17).

Fuel (Table D-13). Profile descent flights used an average of 3,054 pounds of fuel. Those flights that flew the procedure to completion used an average of 2,699 pounds, which was 496 pounds less than the 3,195 pound average of flights when the procedure was interrupted. That difference in fuel saved was found to be statistically significant.

Distance (Table D-14) and Time (Tabel D-15). No significance was found between the differences for either distance or time measures regardless whether the procedure was flown to completion or not.

Workload (Table D-16). The significant workload difference between the complete and incomplete flights was a result of the fact that the completed flights utilizing condition 2 procedure required no control clearances as compared to the incomplete flights which were controlled as conventional flights after the procedure was interrupted. The few clearances issued to the complete flights were generally in the vicinity of 8 nmi from the runway, which had no effect on the procedure. Workload for profile descent aircraft was significantly lower than for aircraft at FL230 and below.

Interrupted Procedure Summary (Table D-17). No statistical analysis was made of this measure. The data shown are the average altitude at which the profile descent procedure was interrupted. It should be noted that the altitude is in relation to mean sea level. Using the profile descent (figure 12), the distance from the runway can be determined.

CONDITION 3. The analysis is of two types of high-speed approaches--IATA and delayed flap. Since condition 3 is more complex than conditions 1 and 2, summary tables have been prepared for each measure showing the significant differences within the measures.

Number of Aircraft (Tables D-18 and D-19). About 85 percent of the high-speed approach flights (both IATA and delayed flap) completed the procedure. The number of flights that completed the procedure was significantly greater than the incomplete. However, there was no significant difference between the number of flights that completed each one of the two approach procedures. Tables D-18 and D-19 give the breakdown by entry direction and fuel category.

Fuel (Tables D-20 and D-21). There was significant fuel saving for aircraft that completed the IATA approach compared to the incomplete IATA and incomplete delayed flap approaches. There was no significant difference between complete IATA and complete delayed flap approaches. The average fuel consumed for complete and incomplete approaches resulted in no significant difference, and the same results were found for all IATA and all delayed flap, as well as for all approaches.

Distance (Table D-22 and D-23). The significant differences point out that delayed flap flights, in general, flew greater distances than IATA flights, and that when the delayed flap procedure was complete, the flight distance was less than when the procedure was interrupted.

Time (Table D-24 and D-25). Since time is a function of distance, the significant differences were expected and essentially point out approximately the same results as the flight distance measures. Incomplete procedure flights were in the system for a significantly longer period of time than complete flights, and the flight time for delayed flap flights was longer ($\alpha = 0.05$) than for IATA, with one exception. A significantly greater flight time was shown for incomplete IATA flights compared with complete delayed flaps. When the approach procedures were complete, both the IATA and the delayed flap required just about the same amount of flight time.

Workload (Table D-26 and D-27). The significant differences indicate that complete high-speed approach procedures required less workload than the incomplete procedures, and that there was less workload controlling delayed flap aircraft than IATA.

Interrupted Procedure (Table D-28). No statistical analysis was run on the values of this measure. An interrupted procedure occurred when the speed of an aircraft was reduced below the speed required by the particular procedure. Procedural requirements for IATA and delayed flap approaches established that speeds not below 180 and 210 knots, respectively, be maintained to a point 4.5 nmi from touchdown (1 nmi inside the outer marker). When the speed was reduced below procedural requirements, an altitude measurement was taken. The average altitude at which the high-speed approach procedures were interrupted was 8,457 feet m.s.l., or between 10 and 11 nmi from touchdown. The table shows that the average altitude was slightly higher for delayed flap flights which were interrupted about 12 nmi out. Interruptions of IATA approaches occurred on an average of about 9 nmi out.

CONDITION 4

General. Condition 4 is complex. There are six treatments (table 2):

1. Complete profile descent with complete delayed flaps
2. Complete profile descent with incomplete delayed flaps
3. Incomplete profile descent with complete IATA
4. Incomplete profile descent with incomplete IATA
5. Incomplete profile descent with complete delay flaps
6. Incomplete profile descent with incomplete delay flaps

The omission of complete profile descents with IATA complete and incomplete scores was due to computer limitations in the simulator software, which made a combination of complete profile descent and IATA procedures impossible.

Number of Aircraft (Tables D-29 and D-30). Table D-29 lists the treatments (procedures) summarized from the scores in table D-30. The significant difference between complete profile descent and incomplete profile descent (All Approaches) was because no IATA procedure could be made with a complete profile descent procedure; i.e., profile descent was curtailed upon the initiating of the IATA approach. Since the IATA approach could not be made together with the complete profile descent, IATA procedures occurred only under the incomplete profile descent.

Considering all the procedures, there were significantly more IATA approaches completed than delayed flap approaches, even though the number of aircraft that were planned to make either an IATA or delayed flap approach was nearly equal.

There was no significant difference in the number of flights between condition 4 and the other conditions within the altitude strata of FL230 and below (table D-1).

Fuel. The fuel data for aircraft that operated in the FL240-and-above strata was found to be inconsistent and is not used in the report. Computer Sciences Corporation reported, in a documentation of that company's participation in supporting the simulation, that the average fuel usage per aircraft in condition 4 was 2,891 pounds (reference 6). The average fuel used per aircraft that operated in the FL230-and-below strata was 1,579 pounds (table D-1).

DISTANCE (TABLES D-31 AND D-32a AND b). Table 3 shows an analysis of the statistically significant differences in the distance flown comparisons. In general, the analysis shows that flights which were not allowed to complete the profile descent procedure flew greater distances than those that completed the procedure. It is also shown that delayed flap approach flights, regardless of whether the procedures were flown to completion or not, flew greater distances than IATA approach flights, with one exception. The IATA flights, when the profile descent was interrupted, flew farther than incomplete delayed flap flights which completed the profile descent. However, the data for the latter flight group are based on only two flights. Additionally, the table shows that when all profile descents, complete and incomplete, are considered, the incomplete high-speed approaches flew greater distances than those that were complete.

There was no significant difference found in the distance flown by flights in the FL230-and-below strata in this condition compared with the other test conditions (table D-1).

Time (Tables D-33 and D-34a and b). Since time-in-system is a function of distance, similar significant differences were, in general, found in both measures. The statistical tests used for this measure addressed only the total average time per aircraft.

Table 4 shows an analysis of the statistically significant difference in the time-in-system comparisons.

TABLE 3. ANALYSIS OF DISTANCE FLOWN COMPARISONS

Complete PD/Complete DF	flew statistically significant greater distance than	*Complete PD/Incomplete DF
Incomplete PD/Complete DF		Complete PD/Complete DF
Incomplete PD/Complete DF		*Complete PD/Incomplete DF
Incomplete PD/Complete DF		Incomplete PD/Incomplete DF
Incomplete PD/Complete DF		Incomplete DP/Complete IATA
Incomplete PD/Complete DF		Incomplete PD/Incomplete IATA
Incomplete PD/Incomplete DF		Complete PD/Complete DF
Incomplete PD/Incomplete DF		*Complete PD/Incomplete DF
Incomplete PD/Incomplete DF		Incomplete PD/Complete IATA
Incomplete PD/Incomplete DF		Incomplete PD/Incomplete IATA
Incomplete PD/ALL DF		Complete PD/ALL DF
Incomplete PD/Complete IATA		*Complete PD/Incomplete DF
Incomplete PD/Incomplete IATA		*Complete PD/Incomplete DF
Incomplete PD/ALL Approaches		Complete PD/ALL Approaches
All PD/Incomplete DF		All PD/Complete IATA
All PD/Incomplete DF		All PD/Incomplete IATA
All PD/ALL DF		ALL PD/ALL IATA
All PD/ALL Incomplete Approaches		ALL PD/ALL Complete Approaches

Legend:

*Data values based on two flights
PD—Denotes profile descent
DF—Denotes delayed flap approach
IATA—Denotes IATA approach

TABLE 4. ANALYSIS OF TIME-IN-SYSTEM COMPARISONS

Complete PD/Complete DF	was in the system significantly longer than	*Complete PD/Incomplete DF
Incomplete PD/Complete DF		Complete PD/Complete DF
Incomplete PD/Complete DF		*Complete PD/Incomplete DF
Incomplete PD/Incomplete DF		Complete PD/Complete DF
Incomplete PD/Incomplete DF		*Complete DP/Incomplete DF
Incomplete PD/Incomplete DF		Incomplete PD/Complete IATA
Incomplete PD/Complete IATA		Complete PD/Complete DF
Incomplete PD/Complete IATA		*Complete PD/Incomplete DF
Incomplete PD/Incomplete IATA		*Complete PD/Incomplete DF
Incomplete PD/All Approaches		Complete PD/All Approaches
All PD/Incomplete DF		ALL PD/Complete DF
ALL PD/Incomplete DF		ALL PD/Complete IATA
ALL PD/Incomplete IATA		ALL PD/Complete IATA
All PD/ALL Incomplete Approaches		All PD/ALL Complete Approaches

Legend:

*Data values based on two flights
PD—Denotes profile descent
DF—Denotes delayed flap approach
IATA—Denotes IATA approach

Incomplete profile descent flights were in the system for a longer time than those when the procedure was flown to completion. The pattern for the high-speed approach portion of the flights was not found to be as consistent. Greater or lesser time-in-system was found to vacillate between the two types of high-speed aproaches and between the completion and incompletion of the approach procedures. However, when both the complete and incomplete profile descents were considered together, the incomplete high-speed approach flights were in the system longer than those that completed the approach procedure.

Workload (Tables D-35 and D-36a and b). The summary, table D-35, depicts the accumulative average of vector, speed, and altitude clearances per aircraft. A breakdown of the workload by the three types of clearances is shown in tables D-36a and D-36b, and an analysis of statistically significant comparisons is shown in table 5.

Table 5 shows that, without exception, controller workload was less when the profile descent portion of the flight was flown to completion regardless of the type of approach or whether the approach procedure was flown to completion or not. It is also shown that, without regard for the complete or incomplete results of the descent procedure during the flight, less workload was required to control completed approaches than incomplete. In general, there was less workload involved in controlling delayed flap approaches than IATA, with one exception. Workload for incomplete delayed flap flights was higher than for complete IATA flights.

Interrupted Procedure (Table D-37a and b). Table 37a lists the altitude at which the delayed flap approach procedure was interrupted after the profile descent procedure had been completed. As previously pointed out, no IATA approaches could be flown following a complete profile descent procedure. Table D-37b lists the interrupted altitude for incomplete profile descents followed by complete and incomplete high-speed approaches. When the high-speed approaches were complete, the interrupted procedure altitude given in the table was the altitude at which the descent procedure was interrupted. In cases where both the profile descent and the high-speed approach procedures were interrupted, the interruption altitudes are shown under the descent and approach columns, respectively.

No statistical analysis was made of the interrupted procedure altitude data for combined treatments. Tables D-37a and b show that on the average, profile descent procedures were interrupted at 11,063 feet (about 20 nmi out) when the high-speed approaches were flown to completion. The interruption altitude for both procedures was approximately the same. When both the profile descent and high-speed approach procedures were interrupted, the interruption of the descent procedure occurred earlier at an altitude of 12,329 feet (about 24 nmi out). The procedure for the high-speed approach portion of the flight was interrupted, on the average, at an altitude of 9,506 feet (about 14 nmi from touchdown). The delayed flap procedure was interrupted earlier at an altitude of 10,379 feet (about 17 nmi from touchdown), and the IATA was interrupted at 8,078 feet (about 10 nmi from touchdown).

TABLE 5. ANALYSIS OF CONTROLLER WORKLOAD COMPARISONS

Incomplete PD/Complete DF	required statistically significant greater workload than	Complete PD/Complete DF
Incomplete PD/Complete DF		*Complete PD/Incomplete DF
Incomplete PD/Incomplete DF		Complete PD/Complete DF
Incomplete PD/Incomplete DF		*Complete PD/Incomplete DF
Incomplete PD/Incomplete DF		Incomplete PD/Complete IATA
Incomplete PD/Complete IATA		Complete PD/Complete DF
Incomplete PD/Complete IATA		*Complete PD/Incomplete DF
Incomplete PD/Incomplete IATA		Complete PD/Complete DF
Incomplete PD/Incomplete IATA		*Complete PD/Incomplete DF
Incomplete PD/Incomplete IATA		Incomplete PD/Complete DF
Incomplete PD/Incomplete IATA		Incomplete PD/Incomplete DF
Incomplete PD/Incomplete IATA		Incomplete PD/Complete IATA
Incomplete PD/ALL Incomplete Approaches		Incomplete PD/ALL Completed Approaches
Incomplete PD/ALL Approaches		Complete PD/ALL Approaches
ALL PD/Incomplete DF		ALL PD/Complete DF
ALL PD/Incomplete DF		ALL PD/Complete IATA
ALL PD/Complete IATA		ALL PD/Complete DF
ALL PD/Incomplete IATA		ALL PD/Complete DF
ALL PD/Incomplete IATA		ALL PD/Incomplete DF
ALL PD/Incomplete IATA		ALL PD/Complete IATA
ALL PD/ALL IATA		ALL PD/ALL DF
ALL PD/ALL Incomplete Approaches		ALL PD/ALL Complete Approaches

Legend:

*Data values based on two flights
PD—Denotes profile descent
DF—Denotes delayed flap approach
IATA—Denotes IATA approach

ANALYSIS

GENERAL.

This discussion of results is based on comparisons of objective data and on the subjective opinion of NAFEC project personnel, participating controllers, and the ARC flight simulator pilots.

Objective data for all entire flights are used in comparisons, except arrival rates, where data from partial flights were used. Comparisons are made between the baseline data of condition 1 (conventional procedures) and the other procedural conditions. Some intraprocedural comparisons are also made.

Table 6 is an excerpt from table D-1 (appendix D) and shows the value of measures per aircraft for flights that operated in both altitude strata, FL240-and-above and FL230-and-below. Data for flights within the higher altitude strata are for all aircraft; that is, the measure values for aircraft that flew a procedure to completion are compiled together with those values for aircraft when the procedure was not completed. These two are referred to as complete and incomplete flights, respectively.

Tables 7 and 8 aid in discussing the complexities in results, and some discussion about what happened within specific areas and/or flight situations is presented. These two tables show data only for aircraft that operated with the FL240-and-above strata. Table 7 shows the measure value difference and percentages of increase or decrease in comparisons of the fuel conservation procedures with the baseline data of the conventional procedures. Data are for all aircraft, and the quadrant of flight is also shown. Table 8 is a summary of measure values per aircraft for only those aircraft that completed the flight-planned procedure. Intermittent reference is made to each of these tables. Positive discussion is presented only where statistically significant differences apply, but reasonable indications and trends are identified as such and discussed where pertinent.

PROFILE DESCENT.

Tables 6 and 7 show that there was a 12-percent ($\alpha = 0.05$) fuel saving of 413 pounds per aircraft with the use of the profile descent procedure as compared to the conventional descent/conventional approach procedure. Additionally, 380 pounds (11 percent) less fuel ($\alpha = 0.05$) per aircraft was used with the profile descent procedure than with the high-speed approach procedures. Evidence of the efficiency of the profile descent procedure is more clearly shown in table 8 where data for only complete procedure flights are considered. Even though the rate of completion for profile descent flights was relatively low, 28 percent, the fuel saving for the complete procedure flights, compared to conventional procedures, was 22 percent or 768 pounds per aircraft.

TABLE 6. GRAND SUMMARY OF MEASURES PER AIRCRAFT BY TEST CONDITION FOR ALL ARRIVAL TRAFFIC

	Test Conditions							
	1		2		3		4	
				FL240 and above				
Fuel	3,467	1*	3,054	1,2	3,434	2		
Distance	152	2	155	1,2	152	1	154	
Time	1,619	1	1,601	2	1,592		1,565	1,2
Workload	6.4	1,2,4	4.0	2,5	5.5	3,4,5	3.9	1,3
				FL230 and below				
Fuel	1,595		1,641	1	1,547	1	1,579	
Distance	127		133		127		129	
Time	2150	2	2,313	1,2	2,100	1	2,288	
Workload	5.9	1	6.6		5.9	2	7.3	1,2

* Significant differences are shown by paired numbers in the same row. For example: The numeral 1 appears following the fuel value for condition 1 at FL240 and above. The numeral 1 also appears following the fuel value for condition 2 in the same row. A significant difference is shown in this manner, and the remainder of the differences shown can be likewise interpreted.

TABLE 7. MEASUREMENT DIFFERENCES COMPARING FUEL CONSERVATION PROCEDURES WITH CONVENTIONAL PROCEDURES

Test Conditions

FL240 and above

Quadrant of Flight	Measures	1	2	3	4
Northeast Keann	Fuel	3,262	-49 2%	-114 3%	
	Distance	145	+4 3%	-2 1%	+1 1%
	Time	1,558	+14 1%	-55 4%	-60 2%
	Workload	5.4	-1.0 19%	-.4 7%	-1.5 28%
Southeast Kiowa	Fuel	3,241	-406 13%	-55 2%	
	Distance	143	0	-1 1%	0
	Time	1,520	-7 0	-8 0	-44 3%
	Workload	6.7	-3.1 46%	-1.3 19%	-2.7 40%
Southwest Byson	Fuel	3,665	-499 14%	-8 0	
	Distance	159	+5 3%	-1 1%	+4 3%
	Time	1,693	-29 2%	-30 2%	-56 3%
	Workload	6.8	-3.3 49%	-.7 10%	-4.0 59%

Quadrant of Flight	Measures	1	2	3	4
Northwest Drako	Fuel	3,872	-522 13%	-60 2%	
	Distance	164	+2 1%	-1 1%	+2 1%
	Time	1,758	-89 5%	-40 2%	-72 4%
	Workload	6.6	-2.2 33%	-1.3 20%	-2.4 36%
System*	Fuel	3,467	413 12%	-33 1%	
	Distance	152	+3 2%	0 0	+2 1%
	Time	1,619	-18 1%	-27 2%	-46 3%
	Workload	6.4	-2.4 38%	-.9 14%	-2.5 39%

* System--the total flying population that operated at FL240 and above, both complete and incomplete flights. Refer to table 6 for indications of statistically significant differences.

TABLE 8. SUMMARY OF MEASURES PER AIRCRAFT BY CONDITION FOR FLIGHTS THAT COMPLETED THE SPECIFIED PROCEDURE, FL240-AND-ABOVE

Measures	Cond. 1 Conventional	Cond. 2 Profile Descent	Cond. 3 High-speed Approaches IATA	Cond. 3 High-speed Approaches DF	Cond. 4 Profile Descent & High-speed Approaches IATA *	Cond. 4 Profile Descent & High-speed Approaches DF **
Number of Aircraft	100%	28%	93%	78%	74%	54%
Fuel	3,467	2,699	3,351	3,480		
Distance	152	153	149	153	152	154
Time	1,619	1,564	1,569	1,585	1,559	1,533
Workload	6.4	.1	5.7	5.0	4.3	1.5
Speed (in knots)	338	352	342	348	351	362

* Simulation procedure did not permit the profile descent to be completed.

** Includes both complete and incomplete profile descents.

Table 7 shows that the beneficial results from the profile descents were equally distributed amongst flights from all directions, except from the northeast over Keann. Trends show that the rate of completion of the procedure for traffic from that direction was lower (table D-12), the altitude at which the procedure was interrupted was higher (table D-7), and the reduction in controller workload was less (table 3) than in any of the other flight direction quadrants.

The profile descent procedure was least compatible with the system functions in the Keann quadrant for several reasons. The semistraight-in design of the azimuth track of the profile descent procedure from over Keann was not as compatible with the dynamic function of the system as the downwind and base-leg pattern from over Drako. The profile descent procedure allowed for no flexibilty in pathstretching or shortcutting, but trends indicate that control judgments and decisions were fewer and less difficult where the downwind and base-leg pattern from Drako was flown, even though the same lack of flexibility prevailed. Even though the procedure and azimuth flight pattern of the profile descent from the Kiowa quadrant was of the same design as that from Keann, comprised of the downwind from over Byson and the semistraight-in from Kiowa, there was a higher degree of operational efficiency because a fewer number of difficult-to-control aircraft entered the final approach area from Kiowa than from Keann. Sixty percent of the traffic volume and 75 percent of the problematic traffic in the FL230-and-below strata from over those two fixes was from Keann.

HIGH-SPEED APPROACH.

Table 6 shows that no significant fuel saving over conventional procedures was found with the high-speed approaches. Only an indication is shown that there might be a trend in favor of less fuel. It can be seen in table 7 that the fuel, distance, time, and workload performance measures, when these procedures were used, were just about the same in all four quadrants. Traffic interactions between the aircraft flying the high-speed approach procedures and low-performance aircraft, as well as between aircraft flying the two different high-speed approach procedures, did not allow for the best efficiency of the high-speed approaches, because sequencing and spacing problems often occurred. Even though about 85 percent of the high-speed approaches were flown to completion, when the procedure was interrupted, fuel consumption for the flight, because of the interruption, was just about the same and in some cases more than during conventional descent and approach procedures. Fuel consumption by incomplete approaches was always higher than when the procedure was completed. The greatest difference was 275 pounds or about 8 percent per aircraft in IATA approaches.

Spacing problems sometimes occurred between the two different high-speed procedures because of the 30-knot difference in the two approach speeds. If a delayed flap flight was followed by an IATA, the IATA flight was affected by the faster speed of the delayed flap aircraft. Spacing was increased. The converse was not true. If an IATA flight was followed by a delayed flap, control planning required additional spacing to allow for the 30-knot closure

of the delayed flap flight on the IATA flight ahead. As a result, the system function was not as compatible for delayed flap procedure flights. Regardless of whether the procedure was flown to completion or not, delayed flap flights always flew greater distances and were in the system for longer periods of time than IATA flights. Additionally, the altitude at which the delayed flap procedure was interrupted during incomplete flights average about 500 feet higher than during incomplete IATA flights.

The IATA procedure was more compatible with traffic flow requirements in the final approach area because the approach speed was 30 knots slower than that of the delayed flap procedure. Table 8 shows that 93 percent of the IATA flights were flown to a completion of the procedure. Those completed flights saved 116 pounds of fuel per aircraft, or about 3 percent over conventional approaches. Seventy-eight percent of the delayed flap approach flights were completed, but data show a slight net fuel loss. The apparent lack of efficiency in the procedure is attibuted to the faster approach speed which caused a greater flight distance, 4 nmi farther than IATA approaches and 1 nmi farther than conventional. In some cases, the flight distance of incomplete delayed flap flights was 6 nmi greater than conventional flights.

COMBINED PROFILE DESCENT AND HIGH-SPEED APPROACHES.

Table 6 and 7 show results of the combined profile descents and high-speed approaches in condition 4 to be reasonably consistent with those in conditions 2 and 3. The procedural effect of each, the profile descent and the high-speed approaches, can be seen. Distance flown and workload were just about the same as when the profile descent procedure alone was used in condition 2, and the time-in-system measure was less because of the effect of the higher speeds in both procedures. Performance was just about the same in all four quadrants. However, because the two procedures were combined, complexities occurred which caused a reduction in the completion rate of each procedure. Trends show that profile descents completed were reduced to 20 percent from the 28 percent in condition 2, and table 8 shows that IATA and delayed flap approach completions were reduced from 93 to 74 and from 78 to 54 percent from condition 3 to condition 4, respectively. Workload in controlling IATA flights was found to be higher.

The flight procedural differences are reflected in both the flight distance and flight time measures (table 6). Longer flightpaths were flown when profile descent procedures were used, and flight distances were the same for both the conventional and the high-speed approach procedures. Although not statistically significant, a trend toward the greater flight distance required by the profile descent was indicated when the profile descent and high-speed approaches were combined. However, that greater distance tended to be offset by the high-speed approaches, which did not require an extended flightpath.

The flight times for conventional, profile descent, and high-speed approaches were just about the same (table 6). Aircraft that flew profile descents remained at higher altitudes for longer periods of time, and were thus enabled to fly further during the same length of time because of the faster groundspeeds at the higher altitude.

EFFECTS ON AIRCRAFT FL230 AND BELOW.

Results indicated that the system did not allow aircraft flying at and below FL230 to operate as efficiently when profile descent procedures were used. Even though statistical tests showed a significant difference only in flight time (table 6), which was increased 8 percent, data comparisons showed trends toward increased fuel consumption and a greater flight distance. Data comparisons also indicated a strong trend toward an increase in controller workload. The increase was found to be about 12 percent, with the number of radar vector and altitude change clearances each increasing 25 percent and with a slight decrease in speed control clearances (tables D-10 and D-16). Although there were increases in controller workload from aircraft in all four quadrants, the greatest item was a 100-percent increase in the number of radar vectors to the aircraft from over Drako. A trend toward an increase in delay is also indicated (table D-4).

Except for delay, it did not appear that the high-speed approach procedures were detrimental to the operation of the aircraft in the FL230-and-below strata. The values of all measures, except delay during high-speed approach operations, were just about the same as during conventional procedure operations. Delay was increased 61 percent over conventional procedures (configuration 1). Once in the system, if anything, a slight trend toward greater efficiency was indicated by the nearly 50 pounds less fuel used and almost a minute less in-flight time. Considering all aircraft that operated in the FL230-and-below strata, there were no significant differences in controller workload. However, when each type of clearance was examined, a trend toward an increase in workload was again found in just about the same pattern as with the profile descent procedures. There were increases in the number of both radar vectors and altitude change clearances of 10 and 25 percent, respectively, and a decrease in the number of speed control clearances (tables D-10 and D-27). The increases were found to have been in controlling the aircraft on the north side of the runway 26L ILS course. It seemed that those on the south side were more compatible with the operation of the high-speed approach procedures and were spaced and sequenced into the flow of high-speed approach aircraft easier than those on the north side. Radar vector and altitude change clearances to aircraft from over Keann and Drako were increased 28, 150, 26, and 27 percent, respectively.

As in configuration 3, except for delay, there was no evidence of detrimental system effects to aircraft in the FL230-and-below strata when the combination of the profile descent and high-speed approach procedures were used in configuration 4. Again, delay was increased (64 percent) over configuration 1. After the aircraft were cleared into the system from the hold, fuel consumption was just about the same as during conventional procedures, and only trends toward increase in flight distance and flight time were shown (table 6). An interesting and important point is that these aircraft posed the greatest problem to ATC at this time, and workload was increased 24 percent (table 6). Again, the familiar pattern of the system effect was evident whereby workload increases were found for radar vectors and altitude change clearances, and aircraft on the north side of the ILS course were more

difficult to control than those on the south. Although workload increases were found in controlling aircraft from all four quadrants, the greatest increases were for Keann and Drako traffic, where radar vectors were increased more than 50 percent and altitude changes between 25 and 40 percent (tables D-10 and D-36a).

During condition 1, when conventional descent and approach procedures were used by aircraft in the FL240-and-above strata, workload was 8 percent higher in controlling the aircraft in the higher altitude strata than in the lower (table 6). That was reversed when the fuel conservative procedures were introduced. Workload in the FL230-and-below strata was 39 percent greater than in the higher strata in condition 2, 7 percent greater in condition 3, and 47 percent greater in condition 4. The effect on workload of the profile descent procedure again is obvious in conditions 2 and 4, but more interesting is that workload in the lower strata in condition 3 is 7 percent greater than in the higher strata—the reversal of workload data indications in condition 1. It is reasonable to conclude that a 15-percent workload increase occurred within the FL230-and-below strata when the high-speed approach procedures were in operation.

ARRIVAL RATES.

The arrival operations rates remained nearly constant throughout all conditions of the experiment. There were no statistically significant differences. The hourly rates averaged between 27.8 and 25.7 for all aircraft that operated in the system in both altitude strata. The hourly rate for aircraft in the higher strata was between 23.1 and 20.8, while in the lower strata the average was from 5.2 to 4.7. The ARC aircraft simulator flights were not included in these data.

DELAY.

There were no significant differences found in the number of aircraft that were delayed in either altitude strata (table D-3). The amount of time lost in delay (table D-4) was significantly greater in conditions 3 and 4 than in conditions 1 and 2 in both altitude strata. There were no differences between conditions 1 and 2 or conditions 3 and 4. None of the aircraft in either altitude strata were penalized significantly by increased delay when profile descents were in operation. Only a slight trend toward increased delay was found. However, when high-speed approaches were in operation (condition 3) and also when the combination of profile descents with high-speed approaches (condition 4) was in operation, delays to aircraft in the FL240-and-above strata were increased between 25 and 30 percent. Delays to aircraft in the FL230-and-below strata, at those times, were increased over 60 percent.

FLIGHT SIMULATORS.

It was planned that the ARC-piloted aircraft simulators were to have been a part of the programed traffic sample input, and each simulator flight was

to have been controlled the same as the computer-generated flights. However, the downtime of both the ARC and NAFEC simulation facilities and other restrictions made the required coordination impossible at times. The programed requirements for the ARC simulators were deviated from, and all of the flights could not be flown. Both simulators flew in all four of the test conditions; however, limited data were available because of the small number of flights. No statistical tests could be made because of the limited amount of data. A trend was, however, shown in favor of fuel saving with the use of the fuel conservative procedures in all the conditions tested. The most favorable indications were in condition 4, when the profile descent and high-speed approach procedures were combined.

Pilot comments were in favor of the fuel conservation procedures, especially the profile descent. However, comments indicated that the charts which had been prepared by NAFEC for use in the simulator cockpits were in excessive detail and should be simplified. Pilot comments were also favorable for dynamic simulation.

INTERACTIONS.

The test design was constrained to four variables (test conditions) because of time limitations for conducting the test. The design did not allow for testing profile descent procedures without the presence of low-performance aircraft in the traffic sample. It is reasonable to conclude that even greater fuel conservation benefits would have been found for the profile descent if traffic interactions with low-performance aircraft could have been eliminated.

Similarly, the test design did not permit testing of the high-speed approach procedures without interaction with low-performance aircraft or without interaction with each other. Again, a reasonable conclusion suggests that favorable results could be attained from high-speed approach procedures being operated within an independent environment.

Severe interaction of traffic often occurred in the final approach airspace because of such a wide range in approach speeds of the different types of aircraft that used the same airspace and landed on the same runway. Analysis of objective data results did not fully demonstrate the magnitude of the many difficult and complex control situations that were observed. Controllers experienced problems in establishing and maintaining a workable sequence of aircraft on the final approach course and maintaining the required spacing to touchdown.

METERING MODEL.

The metering model, which was designed for and used in the simulation, and was intended to aid in sequencing and spacing, was found to be a workable controller's tool. It aided in the orderly dispatch of aircraft entering the area at the peripheral start points. However, because system effects could not be treated in the model, control action was often necessary to assure that

required spacing on final approach was attained. Alternate clearances often changed the patterns of the flows, and the arrangement of the sequence provided by the model were often rearranged. Those actions had a "snowballing" effect and contributed to the number of flights that were not permitted to fly the fuel conservative procedures to completion.

CONTROLLER COMMENTS.

Controllers were critical of the profile descent procedure as it was simulated. Because it was designed essentially to be a "hands off" procedure from cruising level to 7,500 m.s.l. (about 2,200 feet above ground level), no latitude remained for control decisions without interruption of the procedure. Controllers suggested that either the procedure be modified to accommodate control decision adjustments or the metering procedure be refined to treat system effects for more accurate sequencing and spacing.

The terminal ATC procedure was also criticized. The procedure simulated, required the final controller to accept, marshall, and space traffic from over each of the four cornerposts. A possible solution suggested was that flow patterns be modified to enable the north and south arrival controllers to sequence the traffic into a single flow on the respective sides of the ILS course before handoff to the final controller. The final controller would then be accepting traffic flows from two directions instead of four.

DEPARTURES.

There was an indication of about 4-percent saving of fuel when the selected departure flights were not restricted to maintain 250 knots at 10,000 feet and below. However, because of the limited number of test runs, there was not a sufficient amount of data for statistical tests. The elevation of the Denver Stapleton Airport is over 5,000 feet; therefore, the performance of the selected aircraft was measured during slightly less than a 5,000-foot climb. It is reasonable to conclude that a much greater fuel saving would be found in longer climbs from airports at lower elevations above sea level.

HOLDING.

Results of the graphic study of fuel consumption by large turbojet aircraft in holding configurations showed that the most fuel efficient holding altitudes are from 25,000 to 30,000 feet, inclusive. The penalty for holding at 10,000 feet would range from 400 to 1,100 pounds per hour, depending upon the aircraft type.

It was further shown that optimum fuel efficiency while holding is difficult to attain, because holding pattern airspace is often too small to accommodate aircraft flying at the most fuel-efficient speed. When aircraft are required to fly a slower-than-optimum speed to contain the flight pattern within designated airspace, a penalty to fuel efficiency of up to 20 percent results. Additionally, the study showed that in comparison with flight at slower speeds in level flight, holding results in a 5-percent penalty to fuel-flow efficiency.

It was recommended that, wherever possible, the size of holding pattern airspace should be increased, and that delay should be absorbed by slower en route speeds in order to preclude holding. A complete documentation of the study is presented in appendix F.

SUMMARY OF RESULTS

1. The profile descent procedure was significantly efficient in both fuel consumption and controller workload, even though the number of aircraft that completed the profile descent procedure was relatively low.

2. The low rate of completion of the profile descent procedure resulted because of spacing problems and interaction with low-performance aircraft competing to land on the same runway.

3. Spacing and interaction for both high- and low-performance aircraft also adversely affected the high-speed approach operations, making the fuel efficiency of those procedures questionable.

4. The IATA approach procedure was found to be more compatible with traffic flows than the delayed flap, because of the slower approach speed.

5. A reduction in workload was the only advantage found in the simulation of combined profile descent and high-speed approach procedures. That reduction was about the same reduction found for the profile descent procedure alone.

6. The fuel conservation procedures added complexities to the existing complicated flow pattern situations involved in the competition between both high- and low-performance aircraft approaching to land on the same runway. Even though the traffic was metered into the system at the peripheral start points, the model could not treat system effects, and complicated sequencing and spacing problems resulted which were detrimental to the fuel conservation procedures.

7. Arrival operations rates were approximately the same under all conditions tested because traffic was metered into the system.

8. No increase in delay over conventional procedures was incurred by either high- or low-performance aircraft during profile descent operations. However, significant increases in delay occurred for aircraft in both altitude strata during high-speed approach operations and when the profile descent and high-speed approaches were combined.

9. Even though coordination problems did not allow the ARC aircraft simulators to collect sufficient data for analysis, participation was an asset to the simulation because of the realism afforded by the live input.

10. Controller critiques indicated a need for latitude for control decisions and more efficient metering in order to attain more successful results from fuel conservation procedures. Additionally, controllers felt that a redistribution of workload would be a further aid.

CONCLUSIONS

1. The profile descent procedure was significantly efficient in both fuel consumption and in controller workload.

2. Fuel conservation procedures were significantly more efficient in both fuel and controller workload when flown to completion; however, significant benefits were found with the profile descent even when the procedure was interrupted.

3. Air traffic control procedures and techniques have a significant impact on the effectiveness of fuel conservation procedures.

4. Traffic mix adversely effects the results of fuel conservation procedures, especially the high-speed approach procedures.

5. Low-performance aircraft and those not flying fuel conservation procedures should be separated procedurally and approach to land on an independent runway.

6. An effective system of en route metering is mandatory for obtaining efficient results from fuel conservation procedures.

7. Based on the indications of limited data, fuel was saved when the 250-knot speed restriction at 10,000 feet and below was deleted.

RECOMMENDATION

Since fuel conservation has become even more critical subsequent to this study, another full-scaled NAFEC/ARC simulation of fuel conservation procedures should be planned so that the benefits from the evolution of research may be exploited to the fullest. Planning should incorporate a much greater radius of en route range. Planning should also incorporate the latest in fuel optimized procedures, en route metering techniques mandatory to effective scheduling, and provide for on-time delivery of aircraft with the aid of both ground and airborne computing equipments. Studies, thus far, have not been of sufficient depth to investigate the ramifications involved in the marshalling of the flow of arrival traffic, which has been pushed well back into the en route area.

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APPENDIX A

SIMULATION FACILITIES

The ATCSF is a laboratory tool composed of digital computers, a cathode-ray tube complex, a telephone communications system, and a computer-operated radar target generator and data collection system. The computer accepts aircraft performance data, airspace geometry, and flight plan items. The facility provides the capability of realistically modeling, either in real- or fast-time, segments of the ATC system for experimental purposes. Hundreds of aircraft flights can be simulated simultaneously either under the control of simulated ATC facilities or without control intervention.

Under real-time conditions, as with this simulation, air traffic controllers control the flights by issuing clearances through the communications system to the simulator "pilots." Appropriate keyboard entries to the computer are made at the "pilot" operating positions. The clearance vocabulary between controllers and "pilots" is in the same form of clearances that are used in today's ATC system. Detailed information about the simulation facility and associated hardware/software can be obtained by referring to separate NAFEC documents (references 9 and 10).

The piloted aircraft simulators at ARC which "flew" in the NAFEC ATC environment were interconnected with the ATCSF via transcontinental land-line data links. Aircraft identification, altitude, speed, and latitudinal and longitudinal position information were transmitted to NAFEC, and the flights were appropriately positioned on the NAFEC-simulated radar displays at the ATC control positions. Additionally, several voice channels were transmitted via the data link. Thus, the ARC pilots were enabled to be in contact with the appropriate controllers as the flights progressed through the system. Details of the ARC/NAFEC data link can be found in a NASA publication (reference 11).

One of the ARC aircraft simulators was a moving-base transport type capable of simulating a wide range of aircraft during takeoff, climb, cruise, descent, approach, landing, and taxiing. Additional features included out-the-window visual television displays; panel, center, and overhead instruments; programmable "force-feel" flight controls; and autothrottles. In the simulation, this simulator was operated as a fixed base and was configured as a Convair 990 (CV990). The CV990 was simulated, rather than a currently operational aircraft, because NASA has previously conducted both live and simulated tests of the delayed flap high-speed approach procedure with that aircraft.

The second of the ARC aircraft simulators was also capable of specific sophistications similar to the above. In the simulation, it was configured as a Boeing 727.

APPENDIX B

NAFEC/ARC JOINT EFFORT FUEL CONSERVATION SIMULATION OPERATING INSTRUCTIONS FOR CONTROLLERS

BACKGROUND

The rising cost of fuel has precipitated the need for turbojet aircraft to use more economical fuel management techniques. It is anticipated that considerable adjustment and modification to air traffic flows and air traffic control procedures will be necessary to accommodate changes in fuel management procedures.

Air Traffic Service has levied a mandate upon most of the major terminals to implement changes to accommodate profile descent procedures by late 1977. Additionally, the National Aeronautics and Space Administration (NASA) had been conducting studies of two approach procedures designed to conserve fuel; the delayed flap approach, and the International Air Transport Association (IATA) approach.

OBJECTIVE

The objective will be to study the operational impact on air traffic control (ATC) procedures and on air traffic flow patterns when aircraft fuel conservation procedures are used.

PROCEDURES

GENERAL.

The following describes the fuel conservation procedures, air traffic flow and ATC procedures, and simulation procedures.

AREA SIMULATED.

The area simulated will be approximately a 150-mile radius of the Denver Stapleton Airport. All instrument flight rule (IFR) traffic arriving Stapleton Airport will be simulated from peripheral start points to completion of flight at touchdown. All arrival traffic will land on runway 26L, and departures will take off on runway 35R. Departure traffic will be simulated until advised to terminate.

NASA/ARC PILOTED SIMULATORS.

The ARC-piloted flight simulators will participate in the simulation together with the ATCSF computer-generated flights. Actual traffic sample flights will be flown by the flight simulators. One simulator will be configured as a Convair 990, and the other as a Boeing 727, and both will be piloted by current airline pilots. Both of these aircraft will fly conventional procedures, profile descents, and high-speed approaches. The 990 will fly the delayed flap high-speed approach and the 727 will fly the IATA approach. The interface between the ATCSF and the ARC simulators has provided for the capability of discrete communications selection by control operating position.

FUEL CONSERVATION PROCEDURES.

The fuel conservation procedures are the profile descent and the delayed flap and IATA high-speed approaches.

PROFILE DESCENT. Ideally, a profile descent is an uninterrupted descent from cruise altitude to the runway threshold at idle thrust power setting. The descent rate will be about 300 feet per mile. The procedure will be flown by aircraft cruising FL240-and-above, and each flight will be designated by the letter "Z" following the identification in the data tag. The procedure will be flown automatically by the computer-generated flights from start point to touchdown. Due to ATCSF software limitations, any clearance will interrupt the programed profile, and it will be impossible for the profile to be resumed. In the event of an interrupted profile, the "Z" will be dropped from the identification, and it will be necessary to control the flight by conventional methods of navigation and speed control. Wherever possible, attempt to employ a "hands-off" type of control with computer-generated profile descent flights. A diagram of the profile descent procedure for each of the Denver "four corners" will be provided on the back-lighted map displays at each control position in the simulation lab.

The ARC piloted simulators will fly the profile descent procedure without specific clearances. Copies of the profile descent procedures have been prepared for use by the pilots of the simulators during flight. Interruption of the procedure does not necessarily disrupt the entire procedure of the flight; that is, the pilot may be able to resume profile after being interrupted.

DELAYED FLAP APPROACHES. Delayed flap approaches will be flown by aircraft cruising FL240-and-above, and each flight will be designated by the letter "D" following the identification in the data tag. Each aircraft will be assigned a final approach speed of not less than 210 knots, and that speed shall have been attained prior to reaching the ILS final approach course. The speed of 210 knots will be maintained to 4.5 miles from touchdown, where it will be reduced automatically to final speed.

IATA APPROACHES. IATA approaches will be flown by aircraft cruising FL240-and-above, and each flight will be designated by the letter "T" following the identification in the data tag. The IATA procedure requires two speed reductions based on distances from touchdown by DME measurements or controller assistance for the distance measurements. Due to ATCSF software limitations, it will not be possible for these speed reductions to be made automatically, and the speed reductions will be initiated by the final controller. One speed reduction will be made to 180 knots. (The speed of 180 knots is an average and a compromise between the two reductions in the procedure.)

IATA aircraft will be reduced to 180 knots when crossing the 13.5-mile arc which crosses through the ILS course. Any point on the arc is a measured distance of 13.5 from touchdown. The speed of 180 knots will be maintained to 4.5 miles from touchdown, where the reduction to final speed will be made automatically.

CONVENTIONAL DESCENTS AND APPROACHES. All aircraft will be controlled in the conventional manner; that is, aircraft will navigate via VOR routes and radar vectors, and speed control will be used as necessary.

TRAFFIC SAMPLE. The one basic traffic sample was developed from an analysis of a Denver Stapleton Airport busy IFR day in January 1977. The flights were reproduced for simulation, and the number of flights was increased by 20 percent to insure adequate system loading during the tests. The weight class of the aircraft will be shown in the identification line of the data tag as follows:

Heavy - TW123H shows that TWA's flight 123 is a heavy aircraft.

Large - MX234 (no letter following the ident)

Small - RM345S

As discussed above, the profile descent and high-speed approach flight planning for each flight will also be shown on the identification line in the data tag.

Examples are as follows:

TW123H Z shows that the flight is a heavy aircraft and is programed to fly the profile descent procedure.

TW123H D shows that the flight will fly the delayed flap approach procedure. (The letter T would be shown instead of the D in the event the flight was programed to fly the IATA approach instead of the delayed flap.)

TW123H ZD (or ZT) shows that the flight is programed to fly the profile descent and one or the other of the high-speed approach procedures during the same flight.

The one basic traffic sample will be used to test the different procedures. For convenience and ease of identification, each procedure will be associated with a specific sample number as follows:

Sample 1. Aircraft will follow conventional methods of flight during both descent and approach and be controlled by conventional ATC methods.

Sample 2. Profile descent procedures will be in operation and be flown by all aircraft cruising FL240 and above. Aircraft cruising FL230 and below will not fly the profile descent procedure and will be controlled in the conventional manner.

Sample 3. Delayed flap and IATA high-speed approaches will be in operation and be flown by aircraft cruising FL240 and above. The number of aircraft flying each procedure will be divided equally. Aircraft will be controlled by conventional methods during the descent portion of the flights and in accordance with the above described high-speed approach procedures during the approach.

Sample 4. Both the profile descent and high-speed approaches will be in operation. Each aircraft, cruising FL240 and above and according to flight plan, will conform to the profile descent procedure and execute either the delayed flap or IATA approach during the same flight. As in samples 2 and 3, all flights will execute the profile descent, and the number of flights flying each high-speed approach procedure will be divided equally. Again, the aircraft cruising F1230 and below will not fly fuel conservation procedures.

CONTROL POSITIONS. There will be seven operational control positions and controller personnel will be rotated through the positions within areas of specialty. Diagrams of the route structure of the area simulated and the profile descent procedure for each of the Denver "four corners" will be provided on the back-lighted map displays over each of the control positions in the ATCSF control room. The ATCSF laboratory configuration is shown in figure B-1.

Denver Center (ARTCC). The two ARTCC positions will function only as necessary to support the operations of the TRACON. The area will be divided into north and south sectors by the front and back courses of the runway 26L ILS course. With one exception, the controller of each sector will be responsible for arrival traffic originating in and the departure traffic terminating in each respective area of jurisdiction. Eastbound departures via J80 (SID 5) will remain under the control of the Denver North Controller until the flight is terminated, even though a portion of the flight will be flown within the south sector airspace.

Standard ATC service will be provided for arrival and departure traffic. Start clearances will be issued to each flight in accordance with metering model start times as directed by the metering controller. All delays will be accomplished in start point delay, as there is no provision for holding within the area of simulation except in emergencies. Emergency holds may be accomplished at the fixes indicated on the route and flow diagram.

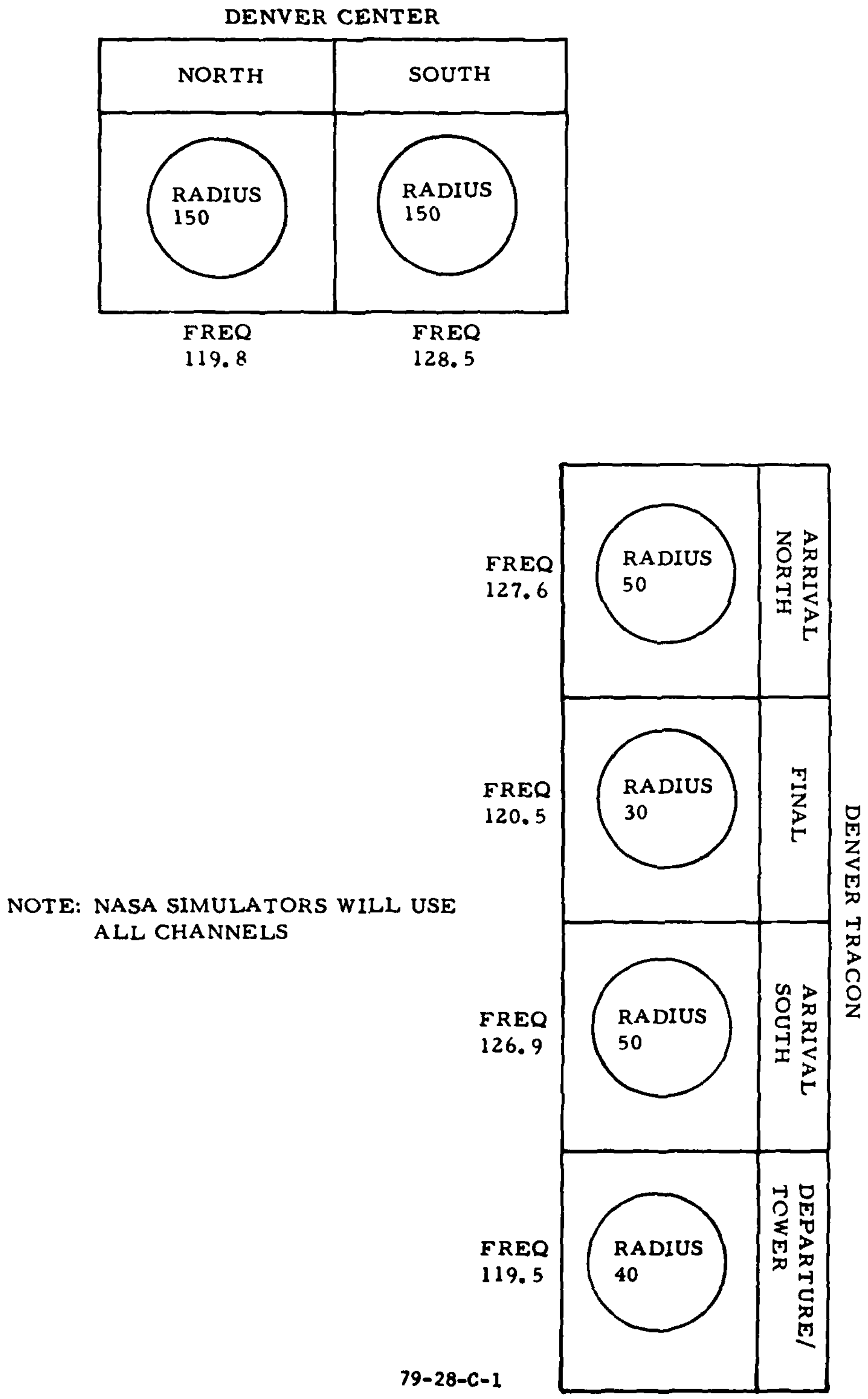

FIGURE B-1. ATCSF LABORATORY DENVER CONFIGURATION

Denver North. Transfer of control of traffic from the northwest routed over Drako and from the northeast routed over Keann will be made to the Denver North Approach Controller at Drako or Smity or no later than when the aircraft leaves 17,000 feet. Unless otherwise directed, departures will be terminated when separation is assured and the aircraft are no longer a factor. This position will control departures eastbound via J80 (SID-5) even though that route is south of the runway 26L ILS course.

Denver South. Transfer of control of traffic from the southwest routed over Byson and from the southeast over Kiowa will be made to the Denver South Approach Controller at Byson or Ramah, respectively, or no later than when the aircraft leaves 17,000 feet. Unless otherwise directed, departures will be terminated when aircraft are no longer a factor and when separation is assured.

Approach Control North. Maintains control of all arrival traffic from over Drako on the northwest and from over Keann on the northeast. Arrivals from over Drako will normally be handed off to the Final Controller over the Denver VORTAC. The aircraft will be given a heading of 075° from the Denver VORTAC and instructed to contact the Final Controller. The aircraft will be descended to maintain an altitude of 8,000 feet. Traffic from over Keann will normally be handed off at Keann. The aircraft will be given a clearance to fly a heading of 170° and descent to 8,000 and instructed to contact the Final Controller.

Approach Control South. Maintains control of all arrival traffic from over Byson on the southwest and from over Kiowa on the southeast. Arrivals from over Byson will normally be handed off to the Final Controller on downwind leg on a heading of 075° descending to maintain 9,000 feet. The handoff will normally be made when the aircraft crosses the Denver 186° radial.

Traffic from over Kiowa will normally be handed off to the Final Controller after the aircraft passes Kiowa on a heading of 310° descending to maintain 9,000 feet.

Approach Control Final. Radar vectors all arrivals to the runway 26L ILS final approach course, sequences and spaces the aircraft, and issues final altitude and ILS approach clearances in the conventional manner.

Special Instructions. The following special instructions shall be observed by both the North and South Arrival Controllers as well as Final. Aircraft identified as being profile descent flights by the letter "Z" will be monitored through the system. No ATC clearances will be required or issued unless necessary for ATC purposes. Aircraft identified as delayed flap approach flights by the letter "D" will not be reduced in speed below 210 knots. Those identified as IATA approach flights by the letter "T" will be given a speed reduction to 180 knots when the aircraft crosses the 13.5-mile arc.

The in-trail spacing between successive aircraft will be:

Leading Aircraft	Trailing Aircraft	Spacing In Miles
Small	Small	3
Small	Large	3
Small	Heavy	3
Large	Small	4
Large	Large	3
Large	Heavy	3
Heavy	Small	6
Heavy	Large	5
Heavy	Heavy	4

Departure/Control Tower. Is responsible for providing separation for departures from the Denver Stapleton Airport. Aircraft will be instructed to maintain runway heading and 10,000 feet for radar vectors to the SID route. All takeoffs will be on runway 35R. Clearance to climb above 10,000 feet will be coordinated with the appropriate approach control position. Radar handoffs will be made to the Denver Center when clear of approach control arriving traffic.

APPENDIX C

METERING MODEL

Flight time from start fix to crossing of the runway threshold was estimated using fast-time simulation of all flights. This information provided a list of all arrival traffic ordered by earliest arrival time (start time plus estimated travel time for that route). The basic time premise of the manual metering procedure was that arrival traffic will land in this sequence.

For each run, a worksheet was prepared as shown in table C-1. The first two columns of information were taken directly from the traffic sample. Column 3 was estimated during fast-time simulation runs. Column 4 is the sum of columns 1 and 2. The aircraft are listed on the worksheet in order by ascending earliest arrival time (column 4). The time separation (column 5) is simply the difference between the earliest arrival time for an aircraft minus the earliest arrival time for the preceding aircraft. (Note: This value is not defined for the first aircraft.)

The minimum separation required (column 6) is determined by the aircraft size class and the approach procedure of the current and preceding aircraft. Tables C-2 and C-3 give the time separation for the possible combinations. The times indicated in these tables are additive.

For example, if the current aircraft is a small aircraft flying a standard approach and the preceding aircraft is a heavy aircraft flying a delayed flap approach, the minimum separation required is 160 seconds plus 60 seconds or 220 seconds.

Column 7 of table C-1 gives the difference between the minimum separation required (column 6) and the actual time separation (column 5). This number represents the delay introduced by each aircraft. (Note: Δ is defined to be zero for the first aircraft.)

The desired delay values for each aircraft (column 8) are computed from the column 7 values. Basically, column 8 is an accumulation of column 7 except that negatives are not allowed. The first entry in column 8 is set to zero. For each subsequent aircraft, the value of Δ in column 7 is added to the delay value of the preceding aircraft from column 8. This value is entered in column 8 unless it is negative. If the new column 8 value is negative, a zero is placed in column 8.

At this point, the worksheet was prepared for the run. If all flights proceed smoothly, each flight should be delayed at the start point by its current delay value. It should be given an actual start time equal to the input start time plus the current delay value. Since the flight times from each start fix may differ, an aircraft which is scheduled to arrive before another aircraft may actually depart its start fix later than the other aircraft.

To handle this situation, each aircraft should be crossed through as it leaves its start fix. By following this procedure, the point at which aircraft start times can be recalculated without changing the arrival sequence can be readily determined. An example is shown in table C-4.

If the terminal area is unable to handle traffic at the expected rate or if some problem occurs which causes a temporary disruption of flow, then the planning must be revised. For this experiment, it was considered that two means of introducing planning changes will be provided.

In the first possibility, either the final controller or the metering controller requests a temporary suspension for some period of time. This request can be honored for all aircraft after the recalculation point (table C-4). The rescheduling is accomplished by readjusting the delay for each aircraft after the recalculation point in order as follows:

1. The additional delay value is added to the column 7 value for the first aircraft after the recompute point.

2. The delay values are recomputed as described above for all aircraft after the recomputation point.

For the second possibility, either the final controller or metering controller requests a change in the nominal time separation between successive aircraft. This situation is handled in a manner very similar to the first case except that the change in time separation is added to the value for each aircraft after the recomputation point and to the end of the list.

The delay values in column 8 (or the new start times equal to the input start time plus delay) must be communicated from the person performing the metering function to the controllers responsible for starting each aircraft.

TABLE C-1. SAMPLE METERING WORKSHEET

ACID	Input Start Time	Estimated Flight Time	Earliest Arrival Time	Time Separation (min:sec)	Minimum Required (min:sec)	(sec)	Delay (sec)
UA317	13:02:13	22:17	13:24:30	-	-	0	0
NA521	12:59:55	25:30	13:25:25	:55	1:20	+25	25
N3216	13:11:22	16:23	13:27:45	:30	2:10	+100	100
AA111H	13:08:00	19:15	13:27:15	1:50	1:20	-30	0
UA83	13:06:16	24:09	13:30:25	2:40	1:20	-80	20
DL507	13:10:43	20:52	13:31:35	1:10	1:20	+10	30
UA660H	13:16:00	17:30	13:33:30	1:55	2:10	+15	45
DL553	13:11:50	24:10	13:36:00	2:30	1:20	-70	0
N2521	13:18:30	19:40	13:38:10	2:10	1:20	-50	0
TW329	13:19:08	19:27	13:38:35	:25	1:20	+55	+55

Current Time: 13:10:00

NOTE: Using this method, start times can be adjusted for those aircraft for which no succeeding aircraft have already started. These aircraft are readily shown by crossing out aircraft as they start. The recomputation point is then the first aircraft after the last one crossed through.

TABLE C-2. TIME SEPARATIONS (SECONDS) FOR AIRCRAFT SIZE CLASS COMBINATIONS

Current Aircraft Size	Preceding Aircraft Size: Heavy	Large	Small
Heavy	110	80	80
Large	135	80	80
Small	160	110	80

TABLE C-3. TIME SEPARATION (SECONDS) FOR AIRCRAFT APPROACH COMBINATIONS

Current Aircraft Approach	Preceding Aircraft Approach: Standard	IATA	Delayed Flap
Standard	0	30	60
IATA	0	0	10
Delayed Flap	0	0	0

TABLE C-4. EXAMPLE RECOMPUTATION POINT

ACID	Input Start Time	Estimated Flight Time	Earliest Arrival Time	Time Separation (min:sec)	Minimum Required (min:sec)	Δ (sec)	Delay (sec)	
N3216	13:11:22	16:23	13:27:45	:30	2:10	+100	100	
DL507	13:10:43	20:52	13:31:35	1:10	1:20	+10	30	Recomputation Point
UA660N	13:16:00	17:30	13:33:30	1:55	2:10	+15	45	
DL553	13:11:50	24:10	13:36:00	2:30	1:20	-70	0	
N2521	13:18:30	19:40	13:38:10	2:10	1:20	-50	0	
TW329	13:19:08	19:27	13:38:35	:25	1:20	+55	+55	

Current Time: 13:10:00

NOTE: Using this method, start times can be adjusted for those aircraft for which no succeeding aircraft have already started. These aircraft are readily shown by crossing out aircraft as they start. The recomputation point is then the first aircraft after the last one crossed through.

APPENDIX D

DATA TABLES

TABLE D-1. GRAND SUMMARY OF MEASURES PER AIRCRAFT BY QUADRANT OF FLIGHT AND TEST CONDITION

Entry Quadrant	Measures	FL240 and Above Test Conditions 1	2	3	4	FL230 and Below Test Conditions 1	2	3	4
Northeast Kean	Aircraft	82	81	73	71	22	24	23	20
	Fuel	3,262	3,213	3,148		1,608	1,724	1,521	1,510
	Distance	145	149	143	146	115	123	108	108
	Time	1,558	1,572	1,503	1,498	2,042	2,117	1,911	2,165
	Workload	5.4	4.4	5.0	3.9	4.9	6.1	5.9	6.5
Southeast Kiowa	Aircraft	67	62	58	59	8	8	8	8
	Fuel	3,241	2,835	3,186		592	580	560	593
	Distance	143	143	142	143	72	71	70	73
	Time	1,520	1,513	1,512	1,476	1,468	1,430	1,424	1,445
	Workload	6.7	3.6	5.4	4.0	6.6	7.6	5.1	8.0
Southwest Byson	Aircraft	84	82	80	83	24	23	24	24
	Fuel	3,665	3,166	3,657		2,024	2,101	2,055	2,056
	Distance	159	164	158	163	148	153	153	154
	Time	1,693	1,664	1,663	1,637	2,094	2,187	2,064	2,072
	Workload	6.8	3.5	6.1	3.8	5.7	6.2	6.1	8.1
Northwest Drako	Aircraft	38	39	46	34	5	8	8	8
	Fuel	3,872	3,350	3,812		1,078	1,133	1,086	1,308
	Distance	164	166	163	166	164	171	162	166
	Time	1,758	1,669	1,718	1,686	3,982	4,149	3,422	4,084
	Workload	6.6	4.4	5.3	4.1	6.5	7.9	6.3	6.5
System	Aircraft	271	264	257	247	59	63	63	60
	Fuel	3,467 1*	3,054 1*,2	3,434 2		1,595	1,641 1	1,547 1	1,579
	Distance	152 2	155 1,2	152 1	154	127	133	127	129
	Time	1,619 1	1,601 2	1,592	1,565 1,2	2,150 2	2,313 1,2	2,100 1	2,288
	Workload	6.4 1,2,4	4.0 2,5	5.5 3,4,5	3.9 1,3	5.9 1	6.6	5.9 2	7.3 1,2

* Significant differences are shown by paired numbers in the same row. For example: The numeral 1 appears following the fuel value *for condition 1 at FL240 and above. The numeral 1 also appears following the fuel value for condition 2 in the same row.* A significant difference is shown in this manner, and the remainder of the differences shown can be likewise interpreted.

TABLE D-2. AVERAGE ARRIVAL RATE PER TEST RUN AND PER HOUR BY QUADRANT, CONDITION, AND ALTITUDE STRATA

FL240 and above

Test Conditions

Direction	1	2	3	4	
Northeast	10.3	10.5	9.4	9.5	
Southeast	8.6	7.6	7.8	7.4	
Southwest	10.6	10.3	10.0	10.4	
Norhtwest	5.1	5.1	5.0	3.9	
Run Avg.	34.6	33.5	32.1	31.1	N S*
Hourly Rate	23.1	22.3	21.4	20.8	N S

FL230 and below

Direction	1	2	3	4	
Northeast	2.7	3.0	2.9	2.4	
Southeast	1.0	1.0	1.0	1.0	
Southwest	3.0	2.9	3.0	3.1	
Northwest	0.6	0.9	0.9	0.9	
Run Avg.	7.3	7.8	7.8	7.4	N S
Hourly Rate	4.7	5.1	5.2	4.9	N S

System Total

	1	2	3	4	
Run Avg.	41.7	41.3	39.9	38.5	N S
Hourly Rate	27.8	27.4	26.6	25.7	N S

* N S = No significant difference between conditions.

TABLE D-3. TOTAL NUMBER OF DELAYED AIRCRAFT BY TEST CONDITION BY QUADRANT AND BY ALTITUDE STRATA

FL240 and above

Test Conditions

Quadrant	1	2	3	4
Northeast	70	72	65	62
Southeast	53	46	45	45
Southwest	61	58	55	60
Northwest	33	35	36	24
Total	217	211	201	191
Run Avg.	27.1	26.4	25.2	23.9 N S*

FL230 and below

Quadrant	1	2	3	4
Northeast	14	14	15	12
Southeast	8	8	8	8
Southwest	23	25	24	25
Northwest	5	6	7	7
Total	50	53	54	52
Run Avg.	6.3	6.6	6.8	6.5 N S
System Total	267	264	255	243
Run Avg.	33.4	33.0	31.9	30.4

* N S = No significant difference between conditions.

TABLE D-4. AVERAGE TOTAL DELAY (SECONDS) PER DELAYED FLIGHT PER RUN BY TEST CONDITION BY QUADRANT BY ALTITUDE STRATA

FL240 and above

Test Conditions

Quadrant	1		2		3		4	
Northeast	506		508		679		766	
Southeast	535		574		767		779	
Southwest	541		455		598		648	
Northwest	588		530		667		792	
FL Avg.	530	2,4*	529	1,3	695	3,4	746	1,2
FL230 and below								
Northeast	666		651		927		912	
Southeast	315		393		505		912	
Southwest	484		651		854		842	
Northwest	820		780		1145		1278	
FL Avg.	527	1,2	612	3,4	851	1,3	863	2,4
System Avg.	517		531		713		761	

* Significant differences shown by paired numbers.

TABLE D-5. CONDITION 1—SUMMARY OF TABLES—NUMBER OR AVERAGE BY MEASURE PER AIRCRAFT

Table Referenced			
D-6	Number of Aircraft		
	Aircraft Cruising FL240 and above	271	
	Aircraft Cruising FL230 and below	59	
	All Aircraft	330	
D-7	Fuel (Average Pounds per Aircraft)		
	Aircraft Cruising FL240 and above	3,467	
	Aircraft Cruising FL230 and below	1,595	
D-8	Distance (Average nmi per Aircraft)		
	Aircraft Cruising FL240 and above	152	
	Aircraft Cruising FL230 and below	127	
D-9	Time (Average Seconds per Aircraft)		
	Aircraft Cruising FL240 and above	1,619	
	Aircraft Cruising FL230 and below	2,150	
D-10	Workload (Average Number of Clearances per Aircraft)		
	Aircraft Cruising FL240 and above	6.4	1
	Aircraft Cruising FL230 and below	5.9	1

1 Significant difference between flight level aircraft.

TABLE D-6. CONDITION 1—NUMBER OF TEST AIRCRAFT BY FUEL CATEGORY AND QUADRANT OF FLIGHT

Aircraft Cruising FL240 and above

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Totals
1	13	0	16	3	32
2	3	5	17	0	25
3	42	40	45	20	147
4	24	22	6	15	67
Total	82	67	84	38	271
Aircraft Cruising FL230 and below					
5	22	8	24	5	59
Quadrant Totals	104	75	108	43	330

TABLE D-7. CONDITION 1—FUEL SUMMARY—AVERAGE NUMBER OF POUNDS USED PER AIRCRAFT BY FUEL CATEGORY AND QUADRANT OF FLIGHT

Aircraft Cruising FL240 and above

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System
1	3,286	0	3,684	4,883	3,635
2	3,425	2,856	3,138	0	3,116
3	3,239	3,270	3,898	3,958	3,547
4	3,270	3,275	3,349	3,556	3,343
Average	3,262	3,241	3,665	3,872	3,467

Aircraft Cruising FL230 and below

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System
5	1,608	592	2,024	1,078	1,595

TABLE D-8. CONDITION 1—DISTANCE FLOWN SUMMARY—AVERAGE NUMBER OF NAUTICAL MILES FLOWN PER AIRCRAFT BY FUEL CATEGORY AND QUADRANT OF FLIGHT

Aircraft Cruising FL240 and above

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System
1	147	0	157	163	154
2	147	145	157	0	154
3	144	143	160	163	151
4	147	143	161	167	151
Average	145	143	159	164	152
Aircraft Cruising FL230 and below					
5	115	72	148	164	127

TABLE D-9. CONDITION 1—TIME-IN-SYSTEM SUMMARY—AVERAGE FLIGHT TIME IN SECONDS PER AIRCRAFT BY FUEL CATEGORY AND QUADRANT OF FLIGHT

	Aircraft Cruising FL240 and above				
	Quadrant of Flight				
Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System
1	1,600	0	1,635	1,770	1,634
2	1,581	1,618	1,714	0	1,679
3	1,557	1,520	1,702	1,753	1,618
4	1,535	1,497	1,721	1,763	1,590
Average	1,585	1,520	1,693	1,758	1,619
	Aircraft Cruising FL230 and below				
5	2,042	1,468	2,094	3,982	2,150

TABLE D-10. CONDITION 1—WORKLOAD SUMMARY—CONTROLLER WORKLOAD BY NUMBER OF RADAR VECTORS, ALTITUDE CHANGE CLEARANCES, AND SPEED CONTROL CLEARANCES BY FUEL CATEGORY AND QUADRANT OF FLIGHT

Aircraft Cruising FL240 and above

Quadrant of Flight

Fuel Category	Northeast Keann			Southeast Kiowa			Southwest Byson			Northwest Drako			System Average		
	V*	S*	A*	V	S	A	V	S	A	V	S	A	V	S	A
1	1.8	2.5	1.2	0	0	0	2.8	1.8	1.6	3.0	2.7	1.0	2.4	2.2	1.4
2	1.3	2.3	1.0	2.8	3.0	1.0	3.0	2.1	1.6	0	0	0	2.8	2.3	1.4
3	2.0	2.1	1.1	3.0	2.4	1.3	2.9	2.4	1.4	3.3	2.5.	1.1	2.7	2.3	1.3
4	2.7	2.4	1.2	3.2	2.1	1.2	3.7	2.0	1.7	3.0	2.5	1.1	3.0	2.3	1.2
Average	2.0	2.3	1.1	3.0	2.5	1.2	3.1	2.1	1.6	3.1	2.4	1.1	2.8	2.3	1.3

Average Number of Clearances per Aircraft = 6.4

Aircraft Cruising FL230 and below

Fuel Category	Northeast Keann			Southeast Kiowa			Southwest Byson			Northwest Drako			System Average		
5	2.9	1.2	.8	3.8	1.3	1.5	3.2	1.8	1.5	3.2	1.8	1.5	3.2	1.5	1.2

Average Number of Clearances per Aircraft = 5.9

*V = radar vectors
S = speed control clearances
A = altitude change clearances

TABLE D-11. CONDITION 2—SUMMARY OF MEASURES TABLE

Table Referenced				
D-12	Number of Aircraft			
	Complete Profile Descents	75	2*	
	Incomplete Profile Descents	189	2	
	All Approaches	264		
	Aircraft Cruising FL230 and below	63		
D-13	Fuel (Average Pounds per Aircraft)			
	Complete Profile Descents	2,699	1	
	Incomplete Profile Descents	3,195	1	
	All Approaches	3,054		
	Aircraft Cruising FL230 and below	1,641		
D-14	Distance (Average nmi per Aircraft)			
	Complete Profile Descents	153		
	Incomplete Profile Descents	156		
	All Approaches	155		
	Aircraft Cruising FL230 and below	133		
D-15	Time (Average Seconds per Aircraft)			
	Complete Profile Descents	1,564		
	Incomplete Profile Descents	1,616		
	All Approaches	1,601		
	Aircraft Cruising FL230 and below	1,641		
D-16	Workload (Average Number of Clearances per Aircraft)			
	Complete Profile Descents	0.1	3	
	Incomplete Profile Descents	5.5	3	4
	All Approaches	4.0	5	
	Aircraft Cruising FL230 and below	6.6	5	4
D-17	Interrupted Profile Descents Altitude (Average)	13,252 feet m.s.l.		

* Significant difference by paired numbers

TABLE D-12. CONDITION 2—NUMBER OF TEST AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT AND PROFILE DESCENT BREAKDOWN

Aircraft Cruising FL240 and above

Complete Profile Descents

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Totals
1	3	0	8	0	11
2	0	0	11	0	11
3	10	13	16	7	46
4	1	2	2	2	7
Total	14	15	37	9	75

Incomplete Profile Descents

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Totals
1	11	0	8	4	23
2	3	2	5	0	10
3	32	27	26	16	101
4	21	18	6	10	55
Total	67	47	45	30	189
Total Profile Descent	81	62	82	39	264

Aircraft Cruising FL230 and below

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Totals
5	24	8	23	8	63
Quadrant Total	105	70	105	47	327

TABLE D-13. CONDITION 2—FUEL SUMMARY—AVERAGE NUMBER OF POUNDS USED PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, AND PROFILE DESCENT BREAKDOWN

Aircraft Cruising at FL240 and above

Complete Profile Descents

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average
1	2,418	0	2,953	0	2,904
2	0	0	2,478	0	2,478
3	2,335	2,525	2,977	2,831	2,688
4	2,865	2,597	2,669	2,991	2,768
Average	2,391	2,535	2,807	2,977	2,699

Incomplete Profile Descents

	*Total[1]	Before[2]	After[3]	Total	Before	After	Total	Before	After	Total	Before	After	Total	Before	After
1	2,844	1,809	1,035	0	0	0	3,788	2,560	1,227	4,386	3,447	938	3,441	2,356	1,086
2	3,126	2,103	1,023	2,056	1,656	400	2,730	2,006	723	0	0	0	2,714	1,966	749
3	2,962	1,658	1,303	2,875	1,793	1,081	3,660	2,585	1,075	3,301	2,317	983	3,172	2,038	1,134
4	3,383	2,155	1,227	3,111	2,319	791	2,763	2,097	666	3,349	2,212	1,137	3,220	2,213	1,007
Average	3,385	1,859	1,223	2,931	1,989	942	3,461	2,452	1,009	3,462	2,433	1,029	3,195	2,124	1,071

System Average 3,054

Average Cruising FL230 and below

5	1,724	580	2,101	1,133	1,641

1 Total—denotes fuel used during entire flight
2 Before—denotes fuel used before profile descent procedures were interrupted
3 After—denotes fuel used after profile descent procedures were interrupted

TABLE D-14. CONDITION 2—DISTANCE FLOWN SUMMARY—AVERAGE NUMBER OF NAUTICAL MILES FLOWN PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, AND PROFILE DESCENT BREAKDOWN

Aircraft Cruising at FL240 and above

Complete Profile Descents

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average
1	145	0	161	0	156
2	0	0	161	0	161
3	141	141	161	162	151
4	145	141	161	162	153
Average	142	141	161	162	153

Incomplete Profile Descents

	*Total[1]	Before[2]	After[3]	Total	Before	After	Total	Before	After	Total	Before	After	Total	Before	After
1	152	118	31	0	0	0	171	135	35	166	136	30	160	127	33
2	149	116	32	141	125	16	169	139	25	0	0	0	156	130	26
3	148	107	40	144	112	32	167	137	30	160	130	30	154	120	34
4	158	113	44	143	113	30	159	134	25	179	128	51	157	119	38
Average	151	111	40	143	113	30	166	137	29	167	130	37	156	121	35

System Average 155

Average Cruising FL230 and below

5	123	71	153	171	133

1 Total—denotes fuel used during entire flight
2 Before—denotes fuel used before profile descent procedures were interrupted
3 After—dentoes fuel used after profile descent procedures were interrupted

CONDITION 2—TIME-IN-SYSTEM SUMMARY—AVERAGE FLIGHT TIME IN SECONDS PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, AND PROFILE DESCENT BREAKDOWN

Aircraft Cruising FL240 and above

Complete Profile Descents

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average
1	1,514	0	1,613	0	1,586
2	0	0	1,650	0	1,650
3	1,451	1,461	1,616	1,639	1,540
4	1,462	1,457	1,613	1,624	1,550
Average	1,465	1,460	1,625	1,631	1,564

Incomplete Profile Descents

	*Total[1]	Before[2]	After[3]	Total	Before	After	Total	Before	After	Total	Before	After	Total	Before	After
1	1,606	1,063	542	0	0	0	1,801	1,186	615	1,658	1,149	508	1,683	1,121	562
2	1,594	1,018	576	1,513	1,211	302	1,727	1,264	463	0	0	0	1,644	1,180	464
3	1,549	964	585	1,540	1,002	537	1,723	1,194	528	1,662	1,146	516	1,609	1,062	547
4	1,656	971	685	1,515	986	529	1,415	805	609	1,716	1,130	585	1,657	1,054	562
Average	1,594	985	609	1,530	1,005	525	1,696	1,148	547	1,680	1,141	538	1,616	1,054	562

System Average 1,601

Aircraft Cruising FL230 and below

5	2,117	1,430	2,187	4,149	2,313

1 Total—denotes fuel used during entire flight
2 Before—denotes fuel used before profile descent procedures were interrupted
3 After—denotes fuel used after profile descent procedures were interrupted

TABLE D-16. CONDITION 2—WORKLOAD SUMMARY—CONTROLLER WORKLOAD BY AVERAGE NUMBER OF RADAR VECTORS, ALTITUDE AND SPEED CLEARANCES PER AIRCRAFT BY FUEL CATEGORY, AND QUADRANT OF FLIGHT AND PROFILE DESCENT BREAKDOWN

Aircraft Cruising FL240 and above

Quadrant of Flight

Complete Profile Descents

Fuel Category	Northeast Keann			Southeast Kiowa			Southwest Byson			Northwest Drako			System Average		
	V*	S*	A*	V	S	A	V	S	A	V	S	A	V	S	A
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	.1	0	0	0	0	0	0	0	0	.1	0	0	.1	0
4	0	0	0	0	.1	0	0	0	0	0	0	0	0	.1	0
Average	0	.1	0	0	.1	0	0	0	0	0	.1	0	0	.1	0

Average Number of Clearances per Aircraft = .1

Incomplete Profile Descents

Fuel Category	Northeast Keann			Southeast Kiowa			Southwest Byson			Northwest Drako			System Average		
	V	S	A	V	S	A	V	S	A	V	S	A	V	S	A
1	1.7	2.2	1.2	0	0	0	3.6	2.3	1.1	3.0	2.3	1.3	2.6	2.3	1.2
2	2.0	2.7	1.0	0	2.0	1.5	3.0	1.4	1.0	0	0	0	2.1	1.9	.9
3	1.6	1.9	1.5	1.5	2.1	.9	3.2	1.8	1.2	2.6	1.9	.9	2.1	1.9	1.1
4	2.0	2.2	1.5	1.5	1.9	1.1	2.1	2.3	1.3	2.7	2.1	1.0	2.2	2.1	1.3
Average	1.8	.2.2	1.3	1.6	2.0	1.0	3.2	1.9	1.2	2.7	2.0	1.0	2.2	2.0	1.3

Average Number of Clearances per Aircraft = 5.5
System Average = 4.0

Aircraft Cruising FL230 and below

Fuel Category	Northeast Keann			Southeast Kiowa			Southwest Byson			Northwest Drako			System Average		
	V	S	A	V	S	A	V	S	A	V	S	A	V	S	A
5	3.6	1.2	1.5	5.1	0.9	1.6	3.3	1.5	1.4	6.4	0.1	1.5	4.0	1.1	1.5

Average Number of Clearances per Aircraft = 6.6

*V = radar vectors
S = speed control clearances
A = altitude change clearances

TABLE D-17. CONDITION 2—INTERRUPTED PROCEDURE ALTITUDE SUMMARY—AVERAGE ALTITUDE AT WHICH PROFILE DESCENT PROCEDURES WERE INTERRUPTED BY FUEL CATEGORY AND QUADRANT OF FLIGHT

	Quadrant of Flight				
Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average
1	12,600	-	12,475	12,818	12,594
2	13,168	9,050	11,390	-	11,455
3	14,178	13,456	11,994	13,282	13,281
4	15,226	12,687	12,042	13,875	13,802
Average	14,202	12,974	12,018	13,427	13,252

* All altitudes are in feet m.s.l.

TABLE D-18. CONDITION 3—NUMBER OF TEST AIRCRAFT—SUMMARY OF TABLE D-19

Complete IATA Approaches	118	3*
Complete Delayed Flap Approaches	101	2
Complete Approaches	219	1
Incomplete IATA Approaches	9	3, 4
Incomplete Delayed Flap Approaches	29	2, 4
Incomplete Approaches	38	1
IATA Approaches	127	
Delayed Flap Approaches	130	
All Approaches	257	
Aircraft Cruising FL230 and below	63	

* Significant differences are indicated by paired numbers.

TABLE D-19. CONDITION 3—NUMBER OF TEST AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, AND APPROACH BREAKDOWN

	Aircraft Cruising FL240 and above: Complete IATA Approaches — Quadrant of Flight					Aircraft Cruising FL240 and above: Incomplete IATA Approaches — Quadrant of Flight					
Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Totals Complete Approaches	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Totals Incomplete Approaches	System Totals All Approaches
1	7	0	7	3	17	1	0	0	0	1	18
2	0	0	15	0	15	0	0	0	0	0	15
3	22	24	1	17	64	2	0	0	4	6	70
4	2	15	5	0	22	0	2	0	0	2	24
	31	39	28	20	118	3	2	0	4	9	127
	Complete Delayed Flap Approaches					Incomplete Delayed Flap Approaches					
1	4	0	8	0	12	1	0	0	0	1	13
2	11	1	3	0	15	1	2	0	0	3	18
3	5	9	35	3	52	3	1	6	4	14	66
4	11	2	0	9	22	3	2	0	6	11	33
	31	12	46	12	101	8	5	6	10	29	130
	62	51	74	32	219	11	7	6	14	38	257
	Aircraft Cruising FL230 and below										
5	23	8	24	8	63						63
										Grand Total	320

TABLE D-20. CONDITION 3—FUEL SUMMARY, SUMMARY OF TABLE D-21

Complete IATA Approaches	3,351	1,* 2
Complete Delayed Flap Approaches	3,480	
Complete Approaches	3,410	
Incomplete IATA Approaches	3,626	1
Incomplete Delayed Flap Approaches	3,555	2
Incomplete Approaches	3,572	
IATA Approaches	3,370	
Delayed Flap Approaches	3,497	
All Approaches	3,434	
Aircraft Cruising FL230 and below	1,547	

*Significant differences are indicated by paired numbers

TABLE D-21. CONDITION 3—FUEL SUMMARY—AVERAGE NUMBER OF POUNDS USED PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, AND APPROACH BREAKDOWN

Aircraft Cruising FL240 and above

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average Complete Approaches
1	3,421	0	3,999	4,261	3,807
2	0	0	3,098	0	3,098
3	3,054	3,221	3,076	3,943	3,353
4	3,276	3,201	3,005	0	3,163
Average	3,151	3,213	3,306	3,991	3,351
Complete Delayed Flap Approaches					
1	3,037	0	3,677	0	3,464
2	3,262	2,488	3,813	0	3,320
3	2,823	3,159	3,841	3,645	3,614
4	3,189	3,145	0	3,422	3,280
Average	3,136	3,101	3,810	3,478	3,480
All Complete Approaches				=	3,410
Aircraft Cruising FL230 and below					
5	1,521	560	2,055	1,086	1,547

Aircraft Cruising FL240 and above

Incomplete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann *Total	Northeast Keann Before	Northeast Keann After	Southeast Kiowa Total	Southeast Kiowa Before	Southeast Kiowa After	Southwest Byson Total	Southwest Byson Before	Southwest Byson After	Northwest Drako Total	Northwest Drako Before	Northwest Drako After	System Average Incomplete Approaches Total	System Average Incomplete Approaches Before	System Average Incomplete Approaches After	System Average
																All IATA Approaches
1	3,472	2,413	1,059	0	0	0	0	0	0	0	0	0	3,472	2,413	1,059	3,370
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	3,507	3,596	311	0	0	0	0	0	0	3,907	3,321	586	3,774	3,279	495	
4	0	0	0	3,258	3,044	215	0	0	0	0	0	0	3,258	3,044	215	
Average	3,495	2,935	560	3,258	3,044	215	0	0	0	3,907	3,321	586	3,226	3,131	495	
Incomplete Delayed Flap Approaches																All Delayed Flap Approaches
1	2,962	2,469	493	0	0	0	0	0	0	0	0	0	2,962	2,469	493	
2	3,364	2,827	537	2,848	2,587	261	0	0	0	0	0	0	3,020	2,667	353	3,497
3	2,808	2,329	479	3,120	2,152	968	4,123	3,358	765	3,835	3,316	519	3,687	3,039	648	
4	3,223	2,392	831	3,483	2,449	1,034	0	0	0	3,805	3,330	475	3,588	2,914	674	
Average	3,054	2,432	620	3,156	2,445	712	4,123	3,358	765	3,817	3,324	493	3,555	2,933	622	
All Incomplete Approaches												=	3,572			All Approaches 3,434

*Total - fuel used during entire flight
Before - fuel used before approach procedures were interrupted
After - fuel used after approach procedures were interrupted

TABLE D-22. CONDITION 3—DISTANCE FLOWN—SUMMARY OF TABLE D-23

Complete IATA Approaches	149	1*, 2
Complete Delayed Flap Approaches	153	1, 4, 5
Complete Approaches	151	
Incomplete IATA Approaches	151	3, 4
Incomplete Delayed Flap Approaches	156	2, 3, 5
Incomplete Approaches	155	
IATA Approaches	149	6
Delayed Flap Approaches	154	6
All Approaches	152	
Aircraft Cruising FL230 and below	127	

*Significant difference is indicated by paired numbers

TABLE D-23. CONDITION 3—DISTANCE FLOWN SUMMARY—AVERAGE NUMBER OF NAUTICAL MILES FLOWN PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, AND APPROACH BREAKDOWN

Aircraft Cruising FL240 and above — Complete IATA Approaches — Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average Complete Approaches
1	146	0	160	158	154
2	0	0	155	0	155
3	142	141	156	160	146
4	146	144	155	0	146
Average	143	142	156	160	149
Complete Delayed Flap Approaches					
1	148	0	156	0	153
2	143	138	160	0	147
3	132	141	160	166	154
4	148	143	0	164	-
Average	143	141	159	165	153
All Complete Approaches				=	151
Aircraft Cruising FL230 and below					
5	108	70	153	162	127

Aircraft Cruising FL240 and above — Incomplete IATA Approaches — Quadrant of Flight

Fuel Category	Northeast Keann *Total	Northeast Keann Before	Northeast Keann After	Southeast Kiowa Total	Southeast Kiowa Before	Southeast Kiowa After	Southwest Byson Total	Southwest Byson Before	Southwest Byson After	Northwest Drako Total	Northwest Drako Before	Northwest Drako After	System Average Incomplete Approaches Total	System Average Incomplete Approaches Before	System Average Incomplete Approaches After	
1	146	120	26	0	0	0	0	0	0	0	0	0	146	120	26	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	148	139	9	0	0	0	0	0	0	159	140	19	155	139	16	All IATA
4	0	0	0	141	133	8	0	0	0	0	0	0	141	133	8	Approaches
Average	147	132	15	141	133	8	0	0	0	159	140	19	151	136	15	149
Incomplete Delayed Flap Approaches																
1	147	131	16	0	0	0	0	0	0	0	0	0	147	131	16	
2	139	123	16	141	129	12	0	0	0	0	0	0	140	127	13	All Delayed
3	134	121	13	144	119	25	165	145	20	166	152	14	157	140	17	Flap
4	145	120	25	146	117	29	0	0	0	171	153	18	159	137	22	Approaches
Average	140	122	18	144	122	22	165	145	20	169	153	16	156	137	19	154
All Incomplete Approaches												=	155			
																System Average All Approaches
																152

*Total - denotes distance flown during entire flight
Before - denotes distance flown before approach procedure was interrupted
After - denotes distance flown after approach procedure was interrupted

TABLE D-24. CONDITION 3—SUMMARY OF TIME-IN-SYSTEM (MINUTES)—SUMMARY OF TABLE D-25

Complete IATA Approaches	1,569	1*, 2
Complete Delayed Flap Approaches	1,585	3, 4
Complete Approaches	1,576	7
Incomplete IATA Approaches	1,645	2, 4, 5
Incomplete Delayed Flap Approaches	1,705	1, 3, 5
Incomplete Approaches	1,691	7
IATA Approaches	1,574	6
Delayed Flap Approaches	1,612	6
All Approaches	1,592	
All Cruising FL230 and below	2,100	

*Significant difference by paired numbers

TABLE D-25. CONDITION 3—AVERAGE TIME-IN-SYSTEM PER AIRCRAFT BY QUADRANT OF FLIGHT, FUEL CATEGORY, AND APPROACH BREAKDOWN

Aircraft Cruising FL240 and above

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average
1	1,577	--	1,732	1,601	1,645
2	--	--	1,673	--	1,673
3	1,487	1,491	1,510	1,669	1,537
4	1,447	1,517	1,609	--	1,532
Average	1,505	1,501	1,671	1,659	1,569
Complete Delayed Flap Approaches					
1	1,564	--	1,580	--	1,575
2	1,464	1,422	1,597	--	1,488
3	1,412	1,516	1,655	1,715	1,611
4	1,521	1,499	--	1,712	1,597
Average	1,489	1,505	1,638	1,713	1,585
Complete Approaches				=	1,576
Aircraft Cruising FL230 and below					
5	1,911	1,424	2,064	3,422	2,100

Aircraft Cruising FL240 and above

Incomplete IATA Approaches

Quadrant of Flight

	Northeast Keann			Southeast Kiowa			Southwest Byson			Northwest Drako			System Average			
	*Total	Before	After	Total	Before	After	Total	Before	After	Total	Before	After	Total	Before	After	
1	1,675	1,139	536	--	--	--	--	--	--	--	--	--	1,675	1,139	536	
2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
3	1,633	1,449	184	--	--	--	--	--	--	1,704	1,391	313	1,680	1,410	270	All IATA Approaches
4	--	--	--	1,524	1,361	163	--	--	--	--	--	--	1,524	1,361	163	
Average	1,647	1,346	301	1,524	1,361	163	--	--	--	1,704	1,391	313	1,645	1,369	276	1,574
Incomplete Delayed Flap Approaches																
1	1,583	1,290	293	1,524	1,361	163	--	--	--	--	--	--	1,583	1,290	293	
2	1,463	1,154	309	1,566	1,352	214	--	--	--	--	--	--	1,532	1,286	246	All Delayed Flap Approaches
3	1,446	1,190	256	1,618	1,110	508	1,822	1,451	371	1,834	1,562	272	1,730	1,402	328	
4	1,528	1,081	447	1,656	1,162	494	--	--	--	1,858	1,572	286	1,731	1,364	367	
Average	1,496	1,157	339	1,612	1,228	384	1,822	1,451	371	1,848	1,568	280	1,705	1,372	333	1,612
Incomplete Approaches												=	1,691			
																All Approaches
																1,592

*Total - denotes flight time during entire flight
Before - denotes flight time before approach procedure was interrupted
After - denotes flight time after approach procedure was interrupted

TABLE D-26. CONDITION 3—CONTROLLER WORKLOAD, AVERAGE NUMBER OF CLEARANCES PER AIRCRAFT—SUMMARY OF TABLE D-27

Complete IATA Approaches	5.7	3*, 4
Complete Delayed Flap Approaches	5.0	1, 1, 4
Complete Approaches	5.4	6
Incomplete IATA Approaches	6.7	1, 3, 5
Incomplete Delayed Flap Approaches	6.7	1, 3, 5
Incomplete Approaches	6.2	6
IATA Approaches	5.8	7
Delayed Flap Approaches	5.2	7
All Approaches	5.5	
Aircraft Cruising FL230 and below	5.9	

*Significant difference is shown by paired numbers

TABLE D-27. CONDITION 3—AVERAGE WORKLOAD PER AIRCRAFT BY CLEARANCE BREAKDOWN, FUEL CATEGORY, QUADRANT OF FLIGHT AND APPROACH BREAKDOWN

Aircraft Cruising FL240 and above

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann V	S	A	Southeast Kiowa V	S	A	Southwest Byson V	S	A	Northwest Drako V	S	A
1	2.1	1.3	1.6	0.0	0.0	0.0	2.6	1.9	1.7	2.0	1.7	1.3
2	0.0	0.0	0.0	0.0	0.0	0.0	3.4	1.7	1.7	0.0	0.0	0.0
3	2.1	1.8	1.3	2.6	2.0	0.9	3.0	3.0	2.0	2.6	1.4	1.4
4	1.5	1.0	1.0	3.0	1.9	1.1	2.6	1.8	1.6	0.0	0.0	0.0
Average	2.1	1.6	1.4	2.6	2.0	1.0	3.0	1.8	1.7	2.5	1.5	1.4

System Average = 2.6 1.8 1.3

Combined = 5.7

Aircraft Cruising FL240 and above

Incomplete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann V	S	A	Southeast Kiowa V	S	A	Southwest Byson V	S	A	Northwest Drako V	S	A
1	1.0	3.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	2.0	3.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	2.5	3.3	1.0
4	0.0	0.0	0.0	4.0	3.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Average	1.0	3.3	1.3	4.0	3.0	1.5	0.0	0.0	0.0	2.5	3.3	1.0

System Average = 2.3 3.2 1.2

Combined = 6.7

All IATA Approaches - System Average = 5.8

Complete Delayed Flap Approaches

Fuel Category	Northeast Keann V	S	A	Southeast Kiowa V	S	A	Southwest Byson V	S	A	Northwest Drako V	S	A
1	3.0	1.3	1.5	0.0	0.0	0.0	2.9	1.3	1.5	0.0	0.0	0.0
2	2.4	1.1	1.4	3.0	1.0	1.0	3.0	1.0	1.0	0.0	0.0	0.0
3	2.0	1.2	1.0	3.1	1.0	0.6	3.1	0.9	1.6	2.3	1.0	1.0
4	1.7	0.9	1.2	2.5	1.0	0.5	0.0	0.0	0.0	2.4	0.7	1.0
Average	2.2	1.1	1.3	3.0	1.0	0.6	3.1	1.0	1.5	2.4	1.0	1.0

System Average = 2.7 1.0 1.3

Combined = 5.0

Incomplete Delayed Flap Approaches

Fuel Category	Northeast Keann V	S	A	Southeast Kiowa V	S	A	Southwest Byson V	S	A	Northwest Drako V	S	A
1	2.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2.0	2.0	1.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	3.0	1.7	1.3	3.0	3.0	1.0	3.3	3.0	1.7	2.8	1.8	1.0
4	2.0	2.3	1.0	2.0	3.5	0.5	0.0	0.0	0.0	2.7	2.0	1.0
Average	2.4	2.0	1.2	2.2	2.4	0.4	3.3	3.0	1.7	2.7	1.9	1.0

System Average = 2.7 2.2 1.1

Combined 6.0

All Delayed Flap Approaches - System Average = 5.2

Complete Approaches—System Average 5.4

Incomplete Approaches—System Average 6.2

System Average - All Approaches 5.5

Aircraft Cruising FL230 and below

Fuel Category	Northeast Keann V	S	A	Southeast Kiowa V	S	A	Southwest Byson V	S	A	Northwest Drako V	S	A
5	3.7	1.0	1.2	3.5	0.5	1.1	3.1	1.3	1.7	4.3	0.1	1.9

System Average 3,5 0.9 1.5
Combined 5.9

*V - radar vectors
S - speed change clearances
A - altitude change clearances

TABLE D-28. CONDITION 3—SUMMARY OF *AVERAGE ALTITUDE AT WHICH THE FUEL CONSERVATION APPROACH PROCEDURES WERE INTERRUPTED

	IATA Approaches				Delayed Flap Approaches			
	Quadrant of Flight				Quadrant of Flight			
Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako
1	8,005	--	--	--	8,171	--	--	--
2	--	--	--	--	9,005	8,987	--	--
3	7,445	--	--	8,196	7,851	9,005	9,438	7,818
4	--	8,466	--	--	9,088	9,005	--	7,981
Average	7,632	8,466	--	8,196	8,499	8,998	9,438	7,916
		System Average =		8,068		System Average =		8,578

System Average - All Approaches = 8,457

*All altitudes are in feet m.s.l.

TABLE D-29. CONDITION 4—NUMBER OF TEST AIRCRAFT—SUMMARY OF TABLE D-30

Complete Profile Descents	50		
Complete IATA Approaches		None	
Complete Delayed Flap Approaches		48	8, 10*
All Complete Approaches		48	
Incomplete IATA Approaches		None	
Incomplete Delayed Flap Approaches		2	8, 11
All Incomplete Approaches		2	
All IATA Approaches		None	
All Delayed Flap Approaches		50	
All Approaches		50	9
Incomplete Profile Descents	197		
Complete IATA Approaches		93	6
Complete Delayed Flap Approaches		17	6, 10
All Complete Approaches		110	7
Incomplete IATA Approaches		33	5
Incomplete Delayed Flap Approaches		54	5, 11
All Incomplete Approaches		87	7
All IATA Approaches		126	4
All Delayed Flap Approaches		71	4
All Approaches		197	9
All Profile Descents	247		
Complete IATA Approaches		93	1
Complete Delayed Flap Approaches		65	1
All Complete Approaches		158	2
Incomplete IATA Approaches		33	3
Incomplete Delayed Flap Approaches		56	3
All Incomplete Approaches		89	2
All IATA Approaches		126	
All Delayed Flap Approaches		121	
All Approaches		247	
Aircraft Cruising FL230 and below	60		
Grand Total	307		

*Significant differences by paired numbers

AD-A088 232 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 1/2
DYNAMIC AIR TRAFFIC CONTROL SIMULATION OF PROFILE DESCENT AND H--ETC(U)
MAY 80 P J O'BRIEN, F M WILLETT, L TOBIAS
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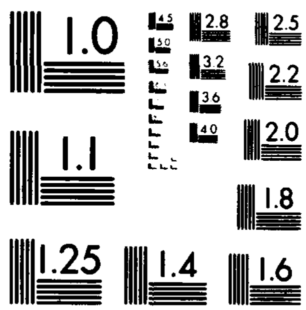

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TABLE D-30. CONDITION 4—NUMBER OF TEST AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, PROFILE DESCENT BREAKDOWN, AND APROACH BREAKDOWN

Aircraft Cruising FL240 and above

Complete IATA Approaches

	Complete Profile Descents					Incomplete Profile Descents					
	Quadrant of Flight					Quadrant of Flight					
Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Totals	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Totals	System Totals
1	0	0	0	0	0	0	0	5	1	9	
2	0	0	0	0	0	0	0	14	1	15	
3	0	0	0	0	0	23	20	0	6	49	
4	0	0	0	0	0	1	13	6	0	20	
	0	0	0	0	0	27	33	25	8	93	93
Complete Delayed Flap Approaches											
1	4	0	7	0	11	1	0	0	0	1	
2	0	0	0	0	0	0	0	0	0	0	
3	4	8	15	2	29	0	1	9	1	11	
4	2	1	0	5	8	5	0	0	0	5	
	10	9	22	7	48	6	1	9	1	17	65
	10	9	22	7	48	33	34	34	9	110	158
Incomplete IATA Approaches											
1	0	0	0	0	0	4	0	2	0	6	
2	0	0	0	0	0	0	0	1	0	1	
3	0	0	0	0	0	11	4	0	8	23	
4	0	0	0	0	0	0	2	1	0	3	
	0	0	0	0	0	15	6	4	8	33	33
Incomplete Delayed Flap Approaches											
1	1	0	0	0	1	2	0	1	0	3	
2	0	0	0	0	0	1	1	1	0	3	
3	0	1	0	0	1	2	6	21	4	33	
4	0	0	0	0	2	7	2	0	6	15	
	1	1	0	0	2	12	9	23	10	54	56
	1	1	0	0	2	27	15	27	18	87	89
Aircraft Cruising FL230 and below											
5	20	8	24	8	60						

TABLE D-31. CONDITION 4—SUMMARY OF DISTANCE FLOWN—SUMMARY OF TABLE 32a AND b

Complete Profile Descents		
Complete IATA Approaches	None	
Complete Delayed Flap Approaches	152	6*,7,11
All Complete Approaches	152	
Incomplete IATA Approaches	None	
Incomplete Delayed Flap Approaches	**143	1,3,6,9,12
All Incomplete Approaches	**143	
All IATA Approaches	None	
All Delayed Flap Approaches	152	14
All Approaches	152	13
Incomplete Profile Descents		
Complete IATA Approaches	152	4,8,9
Complete Delayed Flap Approaches	161	1,2,4,7,10
All Complete Approaches	153	
Incomplete IATA Approaches	151	2,5,12
Incomplete Delayed Flap Approaches	159	3,5,8,10,11
All Incomplete Approaches	156	
All IATA Approaches	151	
All Delayed Flap Approaches	159	14
All Approaches	154	13
All Profile Descents		
Complete IATA Approaches	152	15
Complete Delayed Flap Approaches	154	
All Complete Approaches	153	18
Incomplete IATA Approaches	151	16
Incomplete Delayed Flap Approaches	158	15,16
All Incomplete Approaches	156	18
All IATA Approaches	151	17
All Delayed Flap Approaches	156	17
All Approaches	154	
Aircraft Cruising FL230 and below	129	

*Significant differences are indicated by paired numbers
**Data value based on two flights

TABLE D-32a. CONDITION 4—DISTANCE FLOWN—AVERAGE NUMBER OF NAUTICAL MILES FLOWN PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, PROFILE DESCENT BREAKDOWN, AND APPROACH BREAKDOWN

Aircraft Cruising FL240 and above

Complete Profile Descent

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann *Total	Northeast Keann Descent	Northeast Keann Approach	Southeast Kiowa Total	Southeast Kiowa Descent	Southeast Kiowa Approach	Southwest Byson Total	Southwest Byson Descent	Southwest Byson Approach	Northwest Drako Total	Northwest Drako Descent	Northwest Drako Approach	System Average Total	System Average Descent	System Average Approach
1															
2															
3							NONE								
4															
Complete Delayed Flap Approaches															
1	145	139	6	0	0	0	160	154	6	0	0	0	155	149	6
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	132	126	6	141	135	6	160	154	6	161	155	6	151	145	6
4	145	139	6	141	135	6	0	0	0	161	155	6	152	146	6
Average	139	133	6	141	135	6	160	154	6	161	155	6	152	146	6
Completed Aprchs Avg.	139	133	6	141	135	6	160	154	6	161	155	6	152	146	6
Incomplete IATA Approaches															
1															
2															
3							NONE								
4															
Incomplete Delayed Flap Approaches															
1	145	137	8	0	0	0	0	0	0	0	0	0	145	147	8
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	141	134	7	0	0	0	0	0	0	141	134	7
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	145	137	8	141	134	7	0	0	0	0	0	0	143	135	8
Incomplete Aprchs Avg.	145	137	8	141	134	7	0	0	0	0	0	0	143	135	8
IATA Aprchs Avg.							NONE								
Delayed Flap Aprchs Avg.	140	133	7	141	135	6	160	154	6	161	155	6	152	146	6
All Aprchs Average	140	133	7	141	135	6	160	154	6	161	155	6	152	146	6
Aircraft Cruising FL230 and below															
5	108			73			154			166			129		

1. Total - denotes distance flown during entire flight
2. Descent - denotes distance flown during the descent portion of flight
3. Approach - denotes distance flown during the approach portion of the flight

TABLE 32b. CONDITION 4—DISTANCE FLOWN—AVERAGE NUMBER OF NAUTICAL MILES FLOWN PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, PROFILE DESCENT BREAKDOWN, AND APPROACH BREAKDOWN (Continued)

Aircraft Cruising FL240 and above

Incomplete Profile Descents

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann Total	Northeast Keann Descent	Northeast Keann Approach	Southeast Kiowa Total	Southeast Kiowa Descent	Southeast Kiowa Approach	Southwest Byson Total	Southwest Byson Descent	Southwest Byson Approach	Northwest Drako Total	Northwest Drako Descent	Northwest Drako Approach	System Average Total	System Average Descent	System Average Approach
1	146	125	21	0	0	0	167	133	34	161	147	14	159	132	27
2	0	0	0	0	0	0	162	140	22	175	141	34	163	140	23
3	144	124	20	143	120	23	0	0	0	164	143	31	146	124	22
4	145	125	20	142	124	18	166	146	20	0	0	0	149	131	18
Average	144	124	20	143	122	21	164	140	24	165	143	22	151	129	22
Complete Delayed Flap Approaches															
1	147	121	26	0	0	0	0	0	0	0	0	0	147	121	26
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	144	121	23	166	137	29	173	131	42	165	135	30
4	156	83	73	0	0	0	0	0	0	0	0	0	156	83	73
Average	155	89	66	144	121	23	166	137	29	173	131	42	161	119	42
Completed Aprchs Avg.	146	118	28	143	122	21	165	139	26	166	142	24	153	127	26
Incomplete IATA Approaches															
1	146	119	27	0	0	0	163	135	28	0	0	0	152	124	28
2	0	0	0	0	0	0	163	128	35	0	0	0	167	128	39
3	143	109	34	143	121	22	0	0	0	165	141	24	151	122	29
4	0	0	0	144	113	31	165	138	27	0	0	0	151	121	30
Average	144	112	32	143	118	25	165	134	31	165	141	24	151	122	29
Incomplete Delayed Flap Approaches															
1	143	123	20	0	0	[illegible]	154	96	58	0	0	0	146	116	30
2	147	124	23	141	129	[illegible]	162	141	21	0	0	0	150	131	29
3	132	122	10	148	117	31	162	138	24	167	142	25	158	134	24
4	144	93	51	142	113	29	0	0	0	173	146	27	155	118	29
Average	154	116	38	146	117	29	162	136	26	171	144	27	159	130	29
Incomplete Aprchs Avg.	148	114	34	145	117	28	162	136	26	168	143	25	156	127	29
IATA Aprchs Avg.	144	120	24	143	121	22	164	139	25	165	142	23	151	127	24
Delayed Flap Aprchs Avg.	154	107	47	146	117	29	163	136	27	171	143	28	159	127	27
All Aprchs Average	147	116	31	144	118	26	164	138	26	167	143	24	154	124	30
Grand Total													154	128	26

TABLE D-33. CONDITION 4—TIME-IN-SYSTEM—SUMMARY OF TABLES 34a AND b

	Total	Descent	Approach
Complete Profile Descents			
Complete IATA Approaches		None	
Complete Delayed Flap Approaches	1,509	1,399	110 *2,5,8,9
All Complete Approaches	1,509	1,399	110
Incomplete IATA Approaches		None	
Incomplete Delayed Flap Approaches	**1,481	1,320	161 1,3,6,7,8
All Incomplete Approaches	**1,481	1,320	161
All IATA Approaches		None	
All Delayed Flap Approaches	1,508	1,396	112 16
All Approaches	1,508	1,396	112 11
Incomplete Profile Descents			
Complete IATA Approaches	1,550	1,180	370 4,7,9
Complete Delayed Flap Approaches	1,599	1,028	571 3,5
All Complete Approaches	1,558	1,157	401
Incomplete IATA Approaches	1,585	1,077	508 6
Incomplete Delayed Flap Approaches	1,622	1,129	493 1,2,4
All Incomplete Approaches	1,608	1,109	499
All IATA Approaches	1,559	1,153	406
All Delayed Flap Approaches	1,616	1,105	511 16
All Approaches	1,580	1,135	445 11
All Profile Descents			
Complete IATA Approaches	1,559	1,153	406 13
Complete Delayed Flap Approaches	1,533	1,302	231 12,14
All Complete Approaches	1,544	1,231	313 15
Incomplete IATA Approaches	1,585	1,077	508 14
Incomplete Delayed Flap Approaches	1,617	1,136	481 12,13
All Incomplete Approaches	1,605	1,114	491 15
All IATA Approaches	1,559	1,153	406
All Delayed Flap Approaches	1,571	1,225	346
All Approaches	1,565	1,187	378
Aircraft Cruising FL230 and below	2,288		

*Significant differences are indicated by paired numbers
**Data value based on two flights

TABLE D-32a. CONDITION 4—TIME-IN-SYSTEM—AVERAGE FLIGHT TIME IN SECONDS PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, PROFILE DESCENT BREAKDOWN, AND APPROACH BREAKDOWN

Aircraft Cruising FL240 and above

Complete Profile Descent

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann Total	Northeast Keann Descent	Northeast Keann Approach	Southeast Kiowa Total	Southeast Kiowa Descent	Southeast Kiowa Approach	Southwest Byson Total	Southwest Byson Descent	Southwest Byson Approach	Northwest Drako Total	Northwest Drako Descent	Northwest Drako Approach	System Average Total	System Average Descent	System Average Approach
1 2 3 4							NONE								
Complete Delayed Flap Approaches															
1	1,468	1,375	111	0	0	0	1,568	1,457	111	0	0	0	1,538	1,427	111
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1,368	1,256	112	1,417	1,306	111	1,560	1,447	113	1,604	1,494	110	1,497	1,385	112
4	1,415	1,309	106	1,389	1,283	106	0	0	0	1,573	1,466	107	1,511	1,404	107
Average	1,424	1,314	110	1,413	1,303	110	1,563	1,450	113	1,582	1,474	108	1,509	1,399	110
Completed Aprchs Avg.	1,424	1,314	110	1,413	1,303	110	1,563	1,450	113	1,582	1,474	108	1,509	1,399	110
Incomplete IATA Approaches															
1 2 3 4							NONE								
Incomplete Delayed Flap Approaches															
1	1,514	1,341	173	0	0	0	0	0	0	0	0	0	1,514	1,341	173
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1,447	1,300	147	0	0	0	0	0	0	1,447	1,300	147
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	1,514	1,341	173	1,447	1,300	147	0	0	0	0	0	0	1,481	1,320	161
Incomplete Aprchs Avg.	1,514	1,341	173	1,447	1,300	147	0	0	0	0	0	0	1,481	1,320	161
IATA Aprchs Avg.							NONE								
Delayed Flap Aprchs Avg.	1,435	1,316	117	1,416	1,303	113	1,563	1,450	113	1,582	1,474	108	1,508	1,396	112
All Aprchs Average	1,435	1,316	119	1,416	1,303	113	1,563	1,450	113	1,582	1,474	108	1,508	1,396	112
Aircraft Cruising FL230 and below															
5	2,165			1,445			2,072			4,084			2,288		

TABLE D-34b. CONDITION 4—TIME-IN-SYSTEM—AVERAGE FLIGHT TIME IN SECONDS PER AIRCRAFT BY FUEL CATEGORY, QUADRANT OF FLIGHT, PROFILE DESCENT BREAKDOWN, AND APPROACH BREAKDOWN (Continued)

Aircraft Cruising FL240 and above

Incomplete Profile Descent

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann Total	Northeast Keann Descent	Northeast Keann Approach	Southeast Kiowa Total	Southeast Kiowa Descent	Southeast Kiowa Approach	Southwest Byson Total	Southwest Byson Descent	Southwest Byson Approach	Northwest Drako Total	Northwest Drako Descent	Northwest Drako Approach	System Average Total	System Average Descent	System Average Approach
1	1,517	1,151	366	0	0	0	1,738	1,152	586	1,578	1,308	270	1,647	1,169	478
2	0	0	0	0	0	0	1,651	1,286	365	1,772	1,228	544	1,659	1,282	377
3	1,510	1,160	350	1,475	1,086	389	0	0	0	1,637	1,269	368	1,511	1,146	365
4	1,426	1,299	127	1,445	1,129	316	1,697	1,325	372	0	0	0	1,520	1,196	324
Average	1,507	1,164	343	1,463	1,103	360	1,679	1,269	410	1,647	1,269	378	1,550	1,180	370
Complete Delayed Flap Approaches															
1	1,520	1,107	313	0	0	0	0	0	0	0	0	0	1,520	1,107	313
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1,483	1,117	366	1,643	1,198	445	1,783	1,144	639	1,641	1,186	455
4	1,523	666	857	0	0	0	0	0	0	0	0	0	1,523	666	857
Average	1,523	740	783	1,483	1,117	366	1,643	1,198	446	1,783	1,144	639	1,599	1,028	571
Completed Aprchs Avg.	1,510	1,087	423	1,467	1,103	360	1,669	1,250	419	1,662	1,255	407	1,558	1,157	401
Incomplete IATA Approaches															
1	1,550	1,057	493	0	0	0	1,679	1,175	504	0	0	0	1,593	1,096	497
2	0	0	0	0	0	0	1,753	1,119	634	0	0	0	1,753	1,119	634
3	1,530	957	573	1,474	1,081	393	0	0	0	1,686	1,231	455	1,575	1,074	501
4	0	0	0	1,516	973	543	1,722	1,210	512	0	0	0	1,585	1,052	533
Average	1,535	984	551	1,488	1,045	443	1,708	1,170	538	1,686	1,231	455	1,585	1,077	508
Incomplete Delayed Flap Approaches															
1	1,533	1,134	399	0	0	0	1,538	748	790	0	0	0	1,534	1,038	496
2	1,550	1,127	423	1,488	1,253	235	1,686	1,292	394	0	0	0	1,575	1,224	351
3	1,400	1,187	213	1,606	1,048	558	1,652	1,204	448	1,740	1,287	453	1,639	1,185	454
4	1,471	769	702	1,505	963	542	0	0	0	1,809	1,297	512	1,611	1,006	605
Average	1,476	929	547	1,570	1,052	518	1,649	1,188	461	1,781	1,293	488	1,622	1,129	493
Incomplete Aprchs Avg.	1,509	960	549	1,537	1,049	488	1,658	1,185	472	1,739	1,265	474	1,608	1,109	499
IATA Aprchs Avg.	1,517	1,100	417	1,467	1,095	472	1,683	1,255	428	1,667	1,250	417	1,559	1,153	406
Delayed Flap Aprchs Avg.	1,492	866	626	1,561	1,059	502	1,647	1,191	456	1,781	1,279	502	1,616	1,105	511
All Aprchs Average	1,510	1,029	481	1,488	1.086	402	1,664	1,221	443	1,713	1,262	451	1,580	1,135	445
												Grand Total	1,565	1,187	378

TABLE D-35. CONDITION 4—CONTROLLER WORKLOAD—SUMMARY OF TABLES D-36a AND b

Complete Profile Descents		
Complete IATA Approaches	None	
Complete Delayed Flap Approaches	0.2	7,*9,12,20
All Complete Approaches	0.2	
Incomplete IATA Approaches	None	
Incomplete Delayed Flap Approaches	**1.5	8,11,15,19
All Incomplete Approaches	**1.5	
All IATA Approaches	None	
All Delayed Flap Approaches	0.3	
All Approaches	0.3	21
Incomplete Profile Descents		
Complete IATA Approaches	4.3	10,14,17,18,19,20
Complete Delayed Flap Approaches	5.0	12,13,15,17
All Complete Approaches	4.4	22
Incomplete IATA Approaches	6.5	7,8,10,13,16
Incomplete Delayed Flap Approaches	5.9	9,11,14,16,18
All Incomplete Approaches	5.6	22
All IATA Approaches	4.9	
All Delayed Flap Approaches	5.1	
All Approaches	5.0	21
All Profile Descents		
Complete IATA Approaches	4.3	2,5,6
Complete Delayed Flap Approaches	1.5	1,3,6
All Complete Approaches	3.2	23
Incomplete IATA Approaches	6.5	1,2,4
Incomplete Delayed Flap Approaches	5.0	3,4,5
All Incomplete Approaches	5.5	23
All IATA Approaches	4.9	24
All Delayed Flap Approaches	3.1	24
All Approaches	4.0	
Aircraft Cruising FL230 and below	7.4	

*Significant differences are indicated by paired numbers
**Data value based on two flights

TABLE D-36a. CONDITION 4—AVERAGE CONTROLLER WORKLOAD PER AIRCRAFT BY QUADRANT OF FLIGHT, FUEL CATEGORY, CLEARANCE BREAKDOWN, PROFILE DESCENT BREAKDOWN, AND APPROACH BREAKDOWN

Aircraft Cruising FL240 and above

Complete Profile Descents

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann V*	S*	A*	Southeast Kiowa V	S	A	Southwest Byson V	S	A	Northwest Drako V	S	A	System Average V	S	A
1															
2							None								
3															
4															
Complete Delayed Flap Approaches															
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	0.1	0.1	-	-	-	-	0.1	0.1
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	-	-	-	-	-	-	-	0.1	0.1	-	-	-	-	0.1	0.1
Incomplete IATA Approaches															
1															
2							None								
3															
4															
Incomplete Delayed Flap Approaches															
1	-	2.0	-	-	-	-	-	-	-	-	-	-	-	2.0	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	1.0	-	-	-	-	-	-	-	-	1.0	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	-	2.0	-	-	1.0	-	-	-	-	-	-	-	-	1.5	-
Aircraft Cruising FL230 and below															
5	4.4	1.0	1.1	4.8	1.4	1.8	3.9	1.8	2.4	5.1	.3	1.1	4.4	1.3	1.7

*V—Radar vectors
S—Speed change clearances
A—Altitude change clearances

TABLE D-36b. CONDITION 4—AVERAGE CONTROLLER WORKLOAD PER AIRCRAFT BY QUADRANT OF FLIGHT, FUEL CATEGORY, CLEARANCE BREAKDOWN, PROFILE DESCENT BREAKDOWN, AND APPROACH BREAKDOWN (Continued)

Aircraft Cruising FL240 and above

Incomplete Profile Descents

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann V*	S*	A*	Southeast Kiowa V	S	A	Southwest Byson V	S	A	Northwest Drako V	S	A	System Average V	S	A
1	2.0	1.5	0.5	-	-	-	2.6	1.8	1.8	-	1.0	1.0	2.1	1.6	1.4
2	-	-	-	-	-	-	2.2	0.8	1.4	3.0	2.0	1.0	2.3	0.9	1.4
3	1.3	1.4	1.3	1.8	1.2	1.3	-	-	-	1.5	1.3	1.0	1.5	1.3	1.3
4	-	-	-	1.3	1.5	1.3	1.5	1.3	1.2	-	-	-	1.4	1.4	1.3
Average	1.3	1.4	1.2	1.6	1.3	1.3	2.1	1.1	1.4	1.5	1.4	1.0	1.7	1.3	1.3
Complete Delayed Flap Approaches															
1	2.0	1.0	1.0	-	-	-	-	-	-	-	-	-	2.0	1.0	1.0
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	2.0	1.0	1.0	3.2	.7	1.2	4.0	1.0	1.0	3.2	1.0	1.2
4	2.4	1.0	1.0	-	-	-	-	-	-	-	-	-	2.4	1.0	1.0
Average	2.3	1.0	1.0	2.0	1.0	1.0	3.2	.7	1.2	4.0	1.0	1.0	2.9	1.0	1.1
Complete Aprchs Avg.	1.5	1.3	1.2	1.6	1.3	1.3	2.4	1.0	1.4	1.8	1.4	1.0	1.9	1.3	1.3
Incomplete IATA Approaches															
1	0.8	2.8	1.5	-	-	-	3.0	2.5	2.5	-	-	-	1.5	2.7	1.8
2	-	-	-	-	-	-	2.0	4.0	3.0	-	-	-	2.0	4.0	3.0
3	1.6	2.9	1.6	1.0	3.3	1.5	-	-	-	2.0	2.3	1.5	1.6	2.8	1.6
4	-	-	-	2.0	4.5	3.5	5.0	4.0	1.0	-	-	-	3.0	4.3	2.7
Average	1.4	2.9	1.6	1.3	3.7	2.2	3.3	2.2	1.5	2.0	2.3	1.5	1.7	3.0	1.8
Incomplete Delayed Flap Approaches															
1	-	1.0	1.0	-	-	-	2.0	1.0	1.0	-	-	-	0.7	1.0	1.0
2	2.0	1.0	1.0	-	1.0	1.0	3.0	1.0	1.0	-	-	-	1.7	1.0	1.0
3	-	1.5	0.5	2.5	2.5	1.3	2.1	1.9	1.3	2.3	2.0	0.8	2.1	1.8	1.2
4	1.9	2.4	1.7	1.0	3.5	2.0	-	-	-	1.8	2.3	1.7	1.7	2.5	1.7
Average	1.3	1.9	1.3	1.9	2.6	1.4	2.1	1.8	1.3	2.0	2.2	1.3	1.9	1.9	1.3
Incomplete Aprchs Avg.	1.4	2.5	1.5	1.7	3.0	1.7	2.3	1.9	1.3	2.0	2.2	1.4	1.8	2.3	1.5
IATA Aprchs Avg.	1.3	1.9	1.3	1.6	1.7	1.4	2.3	1.3	1.4	1.8	1.9	1.3	1.7	1.8	1.4
Delayed Flap Aprchs Avg.	1.6	1.6	1.3	1.9	2.4	1.4	2.4	1.5	1.3	2.2	2.1	1.3	2.1	1.7	1.3
All Aprchs Average	1.4	1.8	1.3	1.7	1.8	1.4	2.4	1.4	1.4	2.0	2.0	1.3	1.8	1.8	1.4

*V—Radar vectors
S—Speed change clearances
A—Altitude change clearances

TABLE D-37a. CONDITION 4—*AVERAGE ALTITUDE AT WHICH FUEL CONSERVATION PROCEDURES WERE INTERRUPTED

Complete Profile Descents

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average
1					
2					
3			None		
4					
		Complete Delayed Flap Approaches			
1					
2					
3			None		
4					
		Incomplete IATA Approaches			
1					
2					
3			None		
4					
		Incomplete Delayed Flap Approaches			
1	7,502	-	-	-	7,502
2	-	-	-	-	-
3	-	7,500	-	-	7,500
4	-	-	-	-	-
Average	7,502	7,500	-	-	7,501

*All altitudes are in feet m.s.l.

TABLE D-37b. CONDITION 4—*AVERAGE ALTITUDE AT WHICH FUEL CONSERVATION PROCEDURES WERE INTERRUPTED (Continued)

Incomplete Profile Descents

Complete IATA Approaches

Quadrant of Flight

Fuel Category	Northeast Keann	Southeast Kiowa	Southwest Byson	Northwest Drako	System Average
1	12,184	-	13,272	9,484	12,527
2	-	-	11,596	11,293	11,574
3	10,842	11,252	-	10,703	10,987
4	9,975	9,911	9,843	-	9,786
Average	10,959	10,715	11,417	10,624	10,971
Complete Delayed Flap Approaches					
1	11,782	-	-	-	11,782
2	-	-	-	-	-
3	-	10,372	11,999	14,250	12,056
4	10,463	-	-	-	10,463
Average	10,683	10,372	11,999	14,250	11,571
Complete Aprchs Avg.	10,909	10,705	11,571	11,027	11,063

Incomplete IATA Approaches

	Northeast Keann Decnt	Northeast Keann Aprch	Southeast Kiowa Decnt	Southeast Kiowa Aprch	Southwest Byson Decnt	Southwest Byson Aprch	Northwest Drako Decnt	Northwest Drako Aprch	System Average Decnt	System Average Aprch
1	12,051	7,582	-	-	12,636	8,925	-	-	12,266	8,030
2	-	-	-	-	14,751	6,872	-	-	14,751	6,872
3	14,052	8,152	10,596	7,362	-	-	11,236	8,417	12,471	8,106
4	-	-	12,540	8,123	11,864	8,804	-	-	12,254	8,350
Avg.	13,526	8,000	11,244	7,616	12,972	8,382	11,236	8,417	12,489	8,078
Incomplete Delayed Flap Approaches										
1	11,297	11,297	-	-	14,318	9,003	-	-	12,304	10,532
2	10,825	10,825	8,173	8,173	10,792	10,792	-	-	9,930	9,930
3	7,895	7,895	11,586	10,967	11,906	10,509	11,118	8,835	11,509	9,992
4	17,561	10,996	12,409	11,057	-	-	10,771	10,390	14,134	10,762
Avg.	14,315	10,515	11,390	10,677	12,047	10,456	10,910	9,768	12,231	10,379
Incomplete Aprchs Avg.	13,877	9,118	11,332	8,437	12,116	10,188	11,055	9,168	12,329	9,506

APPENDIX E

FUEL MODEL

The fuel model was developed by Champlain Technology Industries of West Palm Beach, Florida. Modifications were made to the model to meet test requirements. Fuel consumption parameters for use in the model were obtained from the aircraft performance handbook published by the aircraft manufacturer.

To reduce the number of aircraft fuel parameters, the 20 different types of aircraft used in the traffic sample were cataloged under five fuel categories. Each fuel category had an assigned aircraft gross weight. The gross aircraft range from 400,000 pounds for category 1 aircraft to 11,000 pounds for category 5 aircraft. To minimize the stereotype fuel performance within each category, each aircraft was randomly assigned one of three gross weights within the operating limits.

From the flight parameters of assigned gross weight, aircraft altitude, flight condition (level flight, climbing, and descending) and airspeed, the fuel model formula calculated the fuel consumption. Every change in flight parameters required a new calculation of fuel consumption for that period of time.

Examination of the fuel consumption formula showed that reduction in gross weight as fuel is burned off was not considered in the formula. Time limitations did not allow for the necessary software adjustments to allow for that refinement. However, a comparison was made between the amount of fuel used by the ARC Boeing 727 piloted flight simulator and fuel used by a 727 simulated by the ATCSF on several identical flights. Results of that comparison showed that the fuel consumption by both simulators was within an acceptable range of similarity. If anything, the trend was that the fuel model was conservative, and it was concluded that the omission of the gross weight adjustment for final burnoff would not be detrimental to the accuracy of fuel measurements.

Table E-1 shows the arrangement of the simulated aircraft types according to fuel model category and ATCSF category. Each fuel category determined, in accordance with the formula in the model, the fuel flow for each particular type or type group. Categories 1 and 2 were heavy aircraft; large aircraft were in categories 3 and 4; and small aircraft in category 5. Category 5 aircraft operated within the FL230-and-below altitude strata and were not programed to fly the fuel conservation procedures. Fuel conservation procedures were flown by all others.

The simulator category was used to access a specific aircraft type or type group to tables in software for rate and speed performance data.

TABLE E-1. AIRCRAFT TYPES BY FUEL MODEL AND SIMULATOR CATEGORIES

Aircraft Type	Fuel Category	Simulator Category
B-747, DC-10	1	9
DC-8S, B-707, B-720	2	8
B-727, DC-9, B-737	3	10
DC-8, B-707, B-720	4	7
DHC-6	5	1
PA-31, PAZT, BE-90	5	2
CV-58	5	5

APPENDIX F

GRAPHIC STUDY OF FUEL CONSUMPTION DURING IN-FLIGHT HOLDING CONFIGURATIONS

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

NATIONAL AVIATION FACILITIES
EXPERIMENTAL CENTER
ATLANTIC CITY, NEW JERSEY 08405

FEDERAL AVIATION ADMINISTRATION

DATE: April 27, 1979

IN REPLY REFER TO:

SUBJECT: Holding pattern fuel economy for large turbojet aircraft

FROM: John J. Ryan, Project Pilot, ANA-640

TO: P. James O'Brien, ANA-170
Through: Felix Hierbaum, Jr., Project Manager, ANA-170

Introduction:

This study was carried out to provide information relevant to problems associated with fuel consumption in holding patterns. The study had three objectives:

1. To graphically demonstrate and explain the optimum holding altitudes and most efficient airspeeds for several large turbojet aircraft.

2. To show need for more flexibility in allowing for deviations from limit-holding speeds and patterns as specified in FAA procedures.

3. To discuss and identify other means of saving fuel while in a holding pattern.

Background:

With the emphasis on fuel conservation and the constant and increasing threat of energy shortages, fuel savings obtainable in holding patterns must not be overlooked. If holding an aircraft becomes necessary, it is extremely important that ATC be aware of optimum efficient altitude for that particular type. Every possible effort should be made to place the aircraft in the holding pattern not only at their optimum fuel flow altitude but also at their minimum drag airspeed.

Approach:

The performance data of several large turbojet aircraft were examined and drawn up in graphical form to better illustrate the adverse influence of low altitudes on fuel consumption. The conclusions reached were based on figures in FAA approved flight manuals, copies of which are enclosed.

The aircraft examined were: Boeing 727, B-737, B-747, and the DC-10. These aircraft are in wide use by the air carriers in the United States and abroad, and thus present a sufficiently broad spectrum of performance for general conclusions. Performance data from these aircraft, pertinent to this study, are shown in both graphic illustrations and tables in figures F-1 through F-4.

Best Fuel Economy Holding Altitudes

Aircraft	Altitude	Penalty for holding at 10,000 ft instead of best altitude
B-727	25,000 ft	420 lbs/hr
B-737	30,000 ft	520 lbs/hr
B-747	25,000 ft (except when heavy then 20,000 ft)	1100 lbs/hr
DC-10	25,000 ft (except when heavy then 20,000 ft)	500 lbs/hr

Typical Fuel Flow (FF in pounds) for Aircraft at Middle Weight

Aircraft/Gross Wt.	Altitude				
	5,000 ft	10,000 ft	15,000 ft	20,000 ft	25,000 ft
B-727/120,000 GW	6,420 FF	6,240 FF	6,240 FF	6,000 FF	5,820 FF
B-737/85,000 GW	4,720 FF	4,510 FF	4,320 FF	4,170 FF	4,050 FF
B-747/500,000 GW	19,600 FF	19,100 FF	18,700 FF	18,200 FF	18,000 FF
DC-10/320,000 GW	12,600 FF	12,300 FF	12,000 FF	11,800 FF	11,800 FF

Discussion:

The current FAA holding speeds and patterns are as follows: Below 6,000 feet 200 knots/1 minute legs; 6,000 feet to 14,000 feet - 210 knots/1 minute legs, and 14,000 feet and above 230 knots/1-1/2 minute legs.

The data for Boeing 737, Boeing 747 and Douglas DC-10 are minimum drag airspeed. The data for the Boeing 727 is based on FAA holding airspeed limitations.

Comparing these graphs, it is evident that the adherence to the airspeed limits is not fuel efficient. The B-727 graph, Enclosure 1-1, is a perfect example of this. Following the fuel flow lines up to 10,000 feet, the lines have a proper slope, indicating decrease in fuel flow with increasing altitude. However, with the 210 knots constraint, the drag increases (or is not decreasing at higher gross weights) up to 14,000 feet where the aircraft is allowed to accelerate to 230 knots, and fuel flow once again decreases. (The graph is graduated in 5,000 feet increments. The break in fuel flow should be actually at 14,000 feet, although the tabulation implies 15,000 feet). The decrease is evident up to 30,000 feet.

The graphs for the other aircraft are based on minimum drag airspeeds and are not bound by airspeed limits. The fuel flow lines are even and undisturbed, and show gradual fuel flow decrease up to their respective most economical altitude.

Enclosed table "Holding Speed and Fuel Flow" from the B-747 flight manual handbook, Enclosure 2-3, indicates the recommended holding speeds required to achieve minimum fuel flow. The shaded area shows the speeds that are within the limit speed constraints. These speeds represent only 27percent of the conditions, (gross weight/altitude) when the limit speeds can be met. As a result, anytime a B-747 is placed into a holding pattern, the crew has to request permission to exceed the speed limitations. Similar table from a DC-10 manual, Enclosure 2-4, shows a like ratio of only 25 percent of conditions at very light weights when a request for deviation from prescribed airspeeds would not have to be made. In most instances, for the "heavy" aircraft, the limit speeds will have to be exceeded by a hefty margin. For example, holding a DC-10 at 10,000 feet will require up to 50 knots over the speed limit of 210 knots depending on gross weight of the aircraft.

The DC-8 holding speed is one half of gross weight plus 115. For example: 1/2 of 300,000 lbs. G.W. + 115. $\frac{300}{2} = 150 + 115 = 265$. This speed would exceed the ATC limits at all altitudes.

We now have a case when the exception becomes a rule. The FAA should consider a change in the regulations to allow a more fuel efficient flight management. The speed-holding restraints were formulated long before the advent of "heavy" aircraft, and today, with emphasis on fuel conservation, are obsolete. Quote from DC-10-10 FAA Flight Handbook:

1. "Speeds in table are for airplane in the clean configuration."

2. "Flying at lower speeds in the clean configuration <u>will cause drag to increase and speed instability may develop</u>."

All the aircraft can be slowed down to the "proper" speeds by use of lift devices, but at a great penalty. Depending on aircraft type, the amount of fuel flow will increase up to 20 percent for initial flap extension.

Another possible fuel flow reduction is by considerably enlarging the holding patterns. Obviously, this is not possible while holding at the Outer Marker; however, en route and at altitude, consideration should be given to longer legs, if the length of the holding time is known. The data for all large turbojet aircraft shows a 5% increase in fuel flow when the aircraft is flown in a standard racetrack pattern. The first consideration then must be given to slow down en route, before resorting to holding an aircraft. This will save 5 percent of fuel otherwise wasted in a holding pattern.

Conclusions:

1. Make ATC personnel aware of the most fuel efficient holding altitudes for large turbojet aircraft. This could be accomplished mainly by dissemination of this information and charts to the ARTCC facilities.

2. Increase present holding pattern speed limits to more closely correspond to the minimum fuel flow/minimum drag airspeeds of current generation aircraft.

3. Whenever possible, increase the holding pattern size and give the crews more latitude in extending the legs of holding patterns for more fuel efficient operation.

4. Whenever possible, when holding is anticipated, slow down aircraft en-route and at altitude, rather than feeding aircraft into a fuel wasteful holding pattern.

JOHN J. RYAN

2 Enclosures

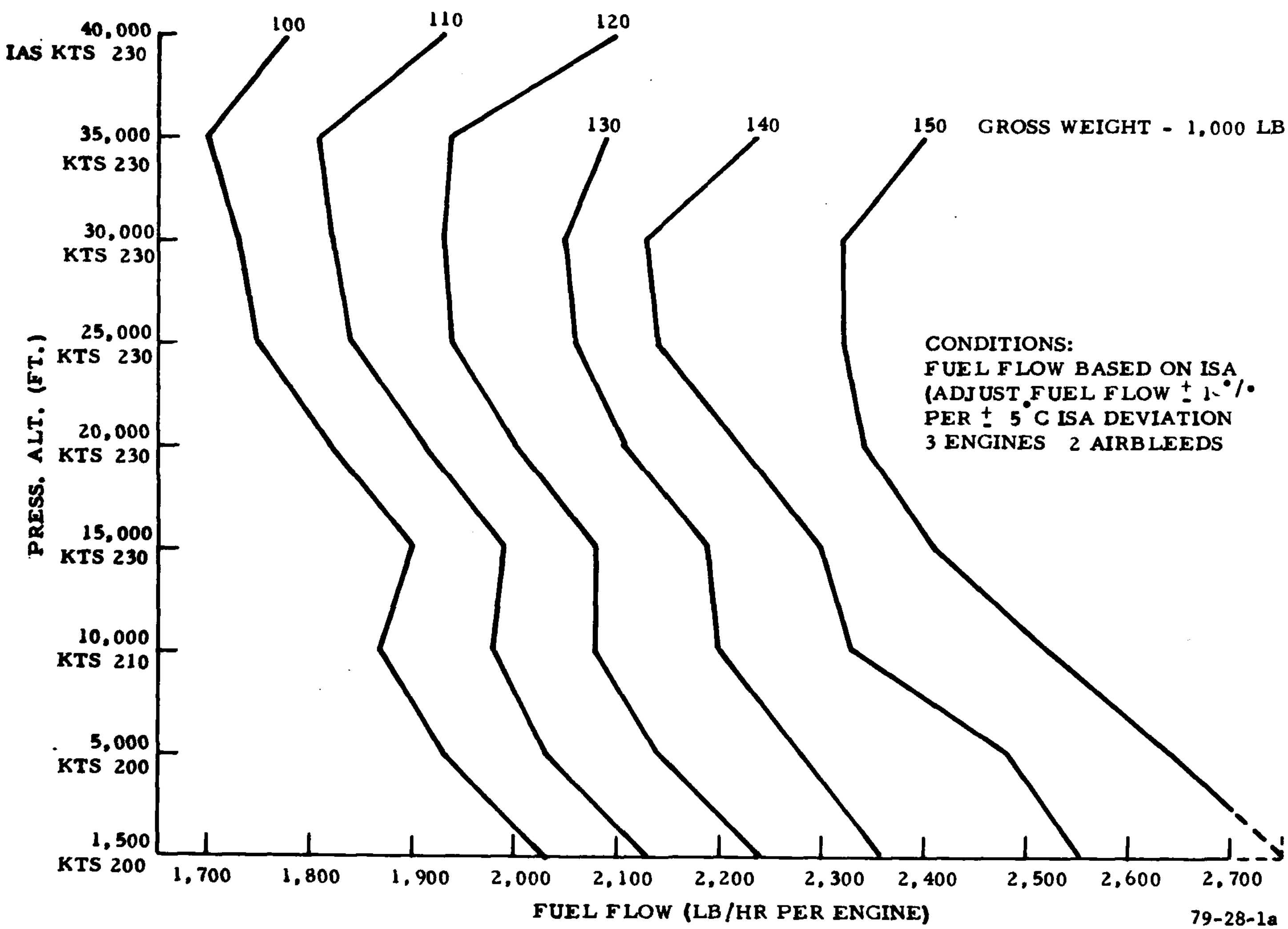
100
110
120
130
140
150
GROSS WEIGHT - 1,000 LB
40,000 IAS KTS 230
35,000 KTS 230
30,000 KTS 230
25,000 KTS 230
20,000 KTS 230
15,000 KTS 230
10,000 KTS 210
5,000 KTS 200
1,500 KTS 200
PRESS. ALT. (FT.)
1,700
1,800
1,900
2,000
2,100
2,200
2,300
2,400
2,500
2,600
2,700
FUEL FLOW (LB/HR PER ENGINE)
CONDITIONS:
FUEL FLOW BASED ON ISA
(ADJUST FUEL FLOW ± 1%
PER ± 5°C ISA DEVIATION
3 ENGINES 2 AIRBLEEDS
79-28-1a

FIGURE F-1

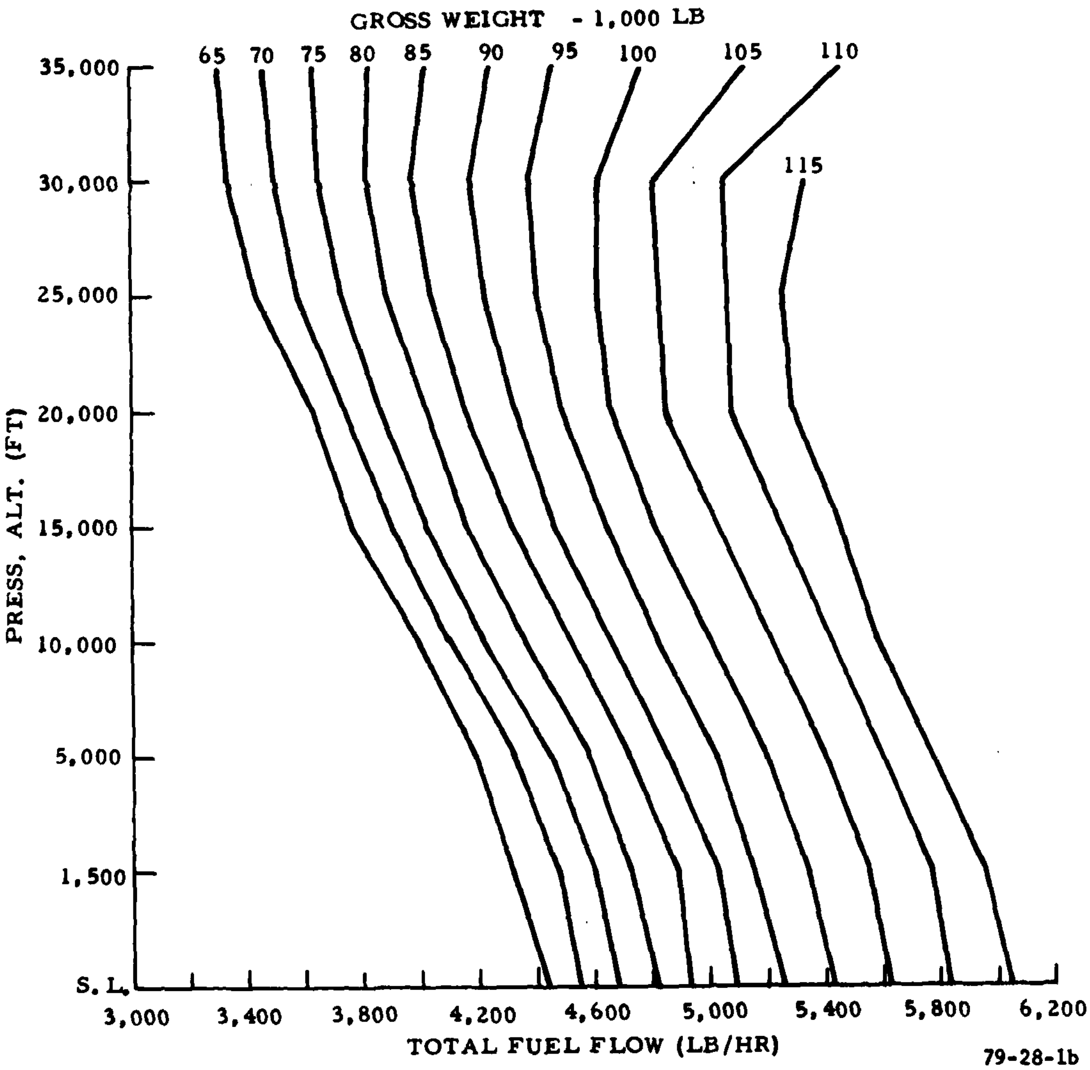
GROSS WEIGHT - 1,000 LB
65
70
75
80
85
90
95
100
105
110
115
PRESS, ALT. (FT)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
1,500
S. L.
3,000
3,400
3,800
4,200
4,600
5,000
5,400
5,800
6,200
TOTAL FUEL FLOW (LB/HR)
79-28-1b

FIGURE F-2

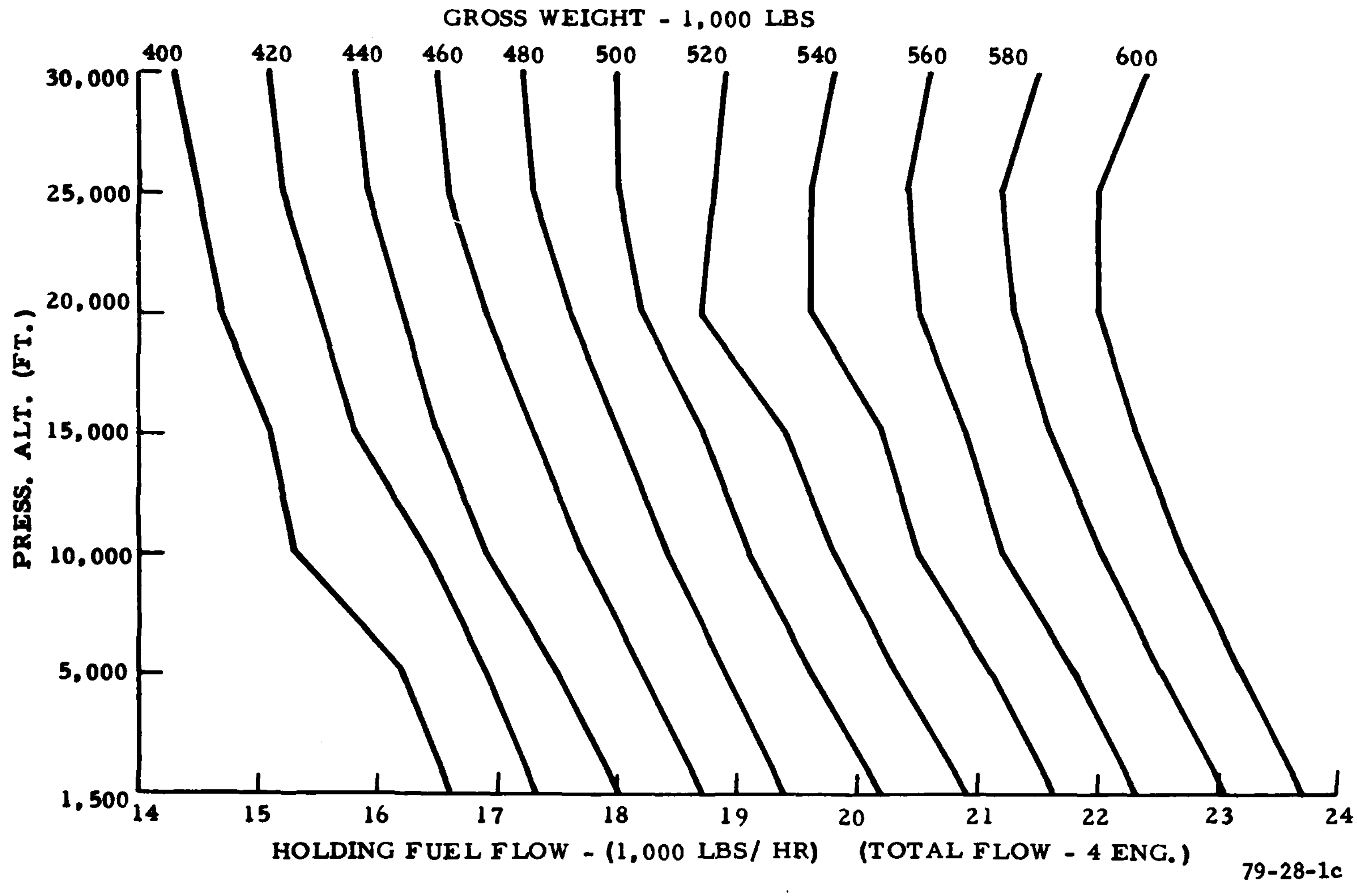
GROSS WEIGHT - 1,000 LBS
400
420
440
460
480
500
520
540
560
580
600
PRESS. ALT. (FT.)
30,000
25,000
20,000
15,000
10,000
5,000
1,500
14
15
16
17
18
19
20
21
22
23
24
HOLDING FUEL FLOW - (1,000 LBS/ HR) (TOTAL FLOW - 4 ENG.)
79-28-1c

FIGURE F-3

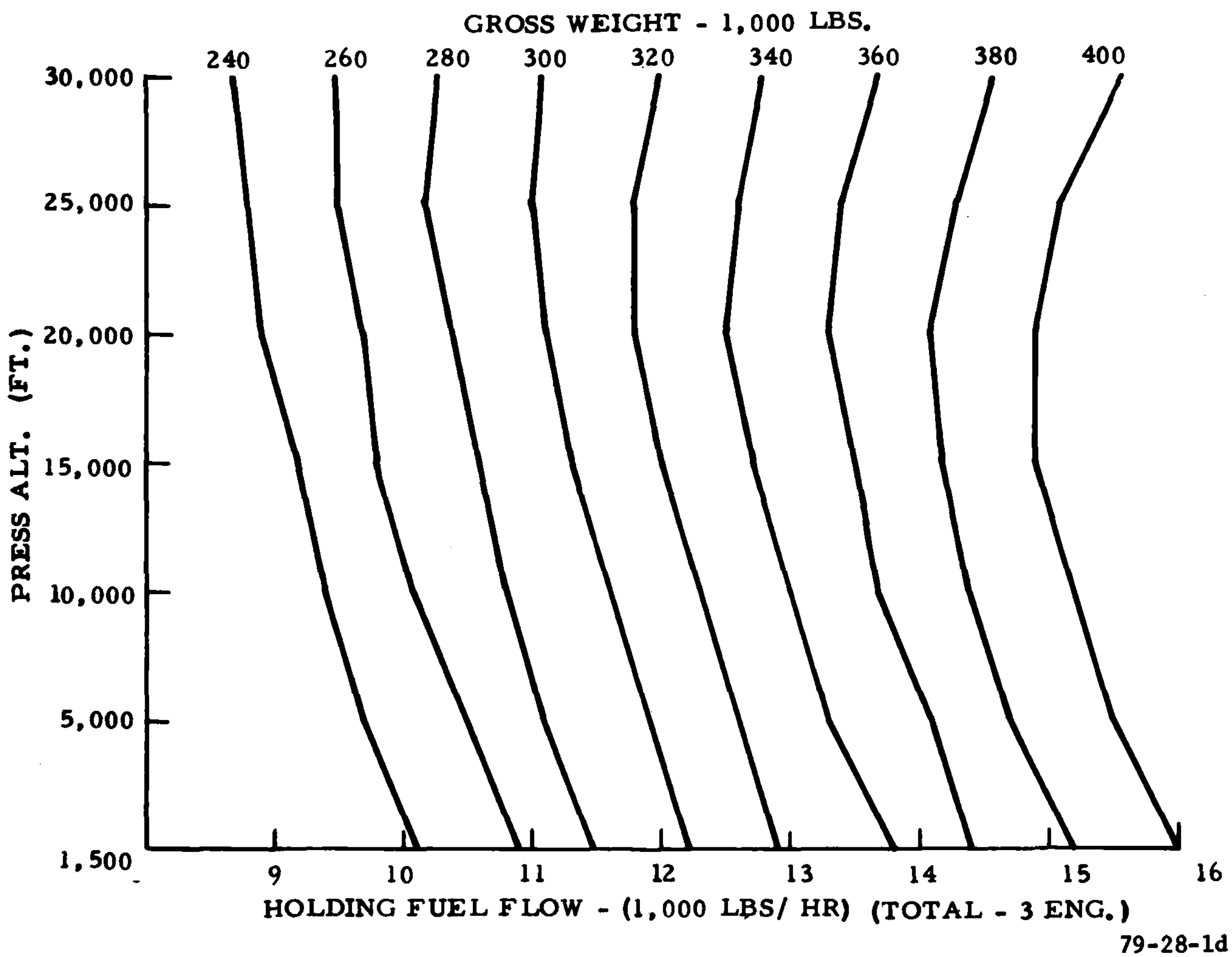
GROSS WEIGHT - 1,000 LBS.
240
260
280
300
320
340
360
380
400
PRESS ALT. (FT.)
30,000
25,000
20,000
15,000
10,000
5,000
1,500
9
10
11
12
13
14
15
16
HOLDING FUEL FLOW - (1,000 LBS/ HR) (TOTAL - 3 ENG.)
79-28-1d

FIGURE F-4

ENCLOSURE 2-1

BOEING 727

HOLDING
3 ENGINES 2 AIRBLEEDS

FAA LIMIT AIRSPEED

EPR
IAS KTS
FF PER ENGINE
STD. DAY TAT °C

FUEL FLOW BASED ON ISA.
ADJUST FUEL FLOW ± 1%
PER ± 5°C ISA DEVIATION

PRESSURE ALTITUDE FT	GROSS WEIGHT — 1000 LB					
	150	140	130	120	110	100
40000				1.96 230 2100 -30	1.88 230 1930 -30	1.81 230 1780 -30
35000	1.95 230 2400 -34	1.88 230 2240 -34	1.82 230 2090 -34	1.75 230 1940 -34	1.70 230 1810 -34	1.65 230 1700 -34
30000	1.76 230 2320 -27	1.71 230 2180 -27	1.66 230 2050 -27	1.61 230 1930 -27	1.56 230 1820 -27	1.52 230 1730 -27
25000	1.61 230 2320 -20	1.57 230 2190 -20	1.53 230 2060 -20	1.49 230 1940 -20	1.45 230 1840 -20	1.42 230 1750 -20
20000	1.49 230 2340 -12	1.46 230 2220 -12	1.42 230 2110 -12	1.39 230 2000 -12	1.36 230 1910 -12	1.34 230 1820 -12
15000	1.39 230 2410 -4	1.36 230 2300 -4	1.34 230 2190 -4	1.31 230 2080 -4	1.29 230 1990 -4	1.27 230 1900 -4
10000	1.34 210 2520 3	1.29 210 2330 3	1.27 210 2200 3	1.24 210 2080 3	1.22 210 1980 3	1.20 210 1870 3
5000	1.28 200 2640 11	1.25 200 2480 11	1.22 200 2280 11	1.19 200 2140 11	1.18 200 2030 11	1.16 200 1930 11
1500	1.25 200 2750 17	1.22 200 2550 17	1.19 200 2360 17	1.17 200 2240 17	1.15 200 2130 17	1.14 200 2030 17

ENCLOSURE 2-2

BOEING 737

HOLDING PLANNING
2 ENGINES 2 AIRBLEEDS

FUEL FLOW BASED ON ISA
ADJUST FUEL FLOW ± 1%
PER ± 5°C ISA DEVIATION

TOTAL FUEL FLOW - LB/HR

PRESS ALT-FT ISA-°C	GROSS WEIGHT - 1000 LB										
	115	110	105	100	95	90	85	80	75	70	65
35000 -54		5480	5120	4790	4480	4250	4030	3830	3640	3470	3310
30000 -44	5340	5070	4810	4620	4390	4190	3990	3820	3660	3500	3360
25000 -35	5270	5070	4850	4620	4410	4230	4050	3890	3730	3580	3450
20000 -25	5290	5070	4850	4670	4500	4330	4170	4020	3880	3740	3620
15000 -15	5440	5230	5020	4810	4640	4480	4320	4170	4030	3900	3770
10000 - 5	5590	5420	5220	5000	4820	4660	4510	4360	4220	4090	3990
5000 5	5780	5600	5400	5200	5030	4870	4720	4590	4460	4330	4200
1500 12	5940	5760	5550	5340	5170	5040	4890	4740	4610	4490	4360
S.L. 15	6030	5830	5620	5430	5270	5110	4960	4820	4690	4560	4420

HOLDING SPEED: 210 KIAS OR MINIMUM DRAG AIRSPEED - CLEAN. FUEL FLOW IS BASED ON HOLDING IN A RACE TRACK PATTERN. REDUCE FUEL FLOW BY 5% IF HOLDING STRAIGHT AND LEVEL.

NOTE: IF HOLDING BELOW 200 KIAS IS REQUIRED, FLAPS POSITION 1 AND 190 KIAS MAY BE MAINTAINED WITH A RESULTING FUEL FLOW INCREASE OF 10%.

ENCLOSURE 2-3

BOEING 747

HOLDING SPEED AND FUEL FLOW

PRESS. ALT-FT		GROSS WEIGHT - 1000 LBS.										
		600	580	560	540	520	500	480	460	440	420	400
30,000	IAS	270	265	260	255	250	245	239	234	229	223	217
	LBS/HR	22400	21500	20600	19800	18900	18000	17200	16500	15800	15100	14300
25,000	IAS	267	262	257	252	247	242	237	232	226	221	215
	LBS/HR	22000	21200	20400	19600	18800	18000	17300	16600	15900	15200	14500
20,000	IAS	264	260	255	250	245	240	235	230	225	220	214
	LBS/HR	22000	21300	20500	19600	18700	18200	17600	16900	16200	15500	14700
15,000	IAS	260	257	252	247	243	238	232	227	222	217	212
	LBS/HR	22300	21600	20900	20200	19400	18700	18000	17300	16500	15800	15100
10,000	IAS	228	225	222	219	216	213	210	207	204	201	198
	LBS/HR	22700	22000	21200	20500	19800	19100	18400	17700	16900	16400	15800
5,000	IAS	228	225	222	219	216	213	210	207	204	201	198
	LBS/HR	23200	22500	21800	21100	20300	19600	18900	18200	17500	16900	16200
	IAS	228	225	222	219	216	213	210	207	204	201	198
1,500	LBS/HR	23700	23000	22300	21600	20900	20150	19400	18700	18000	17300	16600

Total fuel flow for standard day conditions with flaps and landing gear retracted.

Fuel flow will increase approximately 1% for each 5°C increase in temperature and decrease approximately 1% for each 5°C decrease.

Fuel flows based on holding in a race track pattern.

Minimum drag airspeed is shown for 15,000 feet and above. The minimum drag airspeeds represent the best angle of climb speeds.

The airspeed schedule below 15,000 is REF + 80 IAS and is approximately the minimum fuel flow airspeed. Minimum fuel flow airspeeds above 15,000 could not be used because of speed stability problems.

<u>NOTE</u> Outlined area indicates conditions under which limit speeds can be met.

ENCLOSURE 2-4

DC 10

(IAS)

PRESS. ALT.	GROSS WEIGHT - 1000 LBS.								
	400	380	360	340	320	300	280	260	240
30,000	275	268	258	249	241	232	223	213	204
25,000	267	260	252	243	235	227	218	210	202
20,000	263	256	248	240	233	225	217	210	202
15,000	260	254	247	240	233	226	218	211	203
10,000	259	253	247	240	233	227	219	212	203
5,000	258	253	247	241	234	227	220	213	204
1,500	258	253	247	242	236	229	221	213	205

1. Speeds in table are for airplane in the clean configuration, with or without all engine operating.

2. Flying at lower speeds in the clean configuration will cause drag to increase and speed instability may develop.

3. Speeds in table
   - provides adequate speed stability and, for practical purposes, maximum endurance.

NOTE: Outlined area indicates conditions under which limit speeds can be met.

(1000 LBS/HR)

PRESS. ALT.	GROSS WEIGHT - 1000 LBS.								
	400	380	360	340	320	300	280	260	240
30,000	15.6	14.6	13.7	12.8	12.0	11.1	10.3	9.5	8.7
25,000	15.1	14.3	13.4	12.6	11.8	11.0	10.2	9.5	8.8
20,000	14.9	14.1	13.3	12.5	11.8	11.1	10.4	9.7	8.9
15,000	14.9	14.2	13.5	12.7	12.0	11.3	10.6	9.8	9.2
10,000	15.2	14.4	13.7	13.0	12.3	11.6	10.8	10.1	9.4
5,000	15.5	14.7	14.1	13.3	12.6	11.9	11.1	10.5	9.7
1,500	16.0	15.2	14.4	13.8	12.9	12.2	11.5	10.9	10.1

Total fuel flow for straight and level flight at minimum Drag Speeds with flaps, slats and landing gear retracted for Standard Day conditions.

Fuel Flow Adjustments:

Holding in race track pattern	Increase by 5%
Holding with slats extended	Increase by 20%
Temperature - per 5°C above Standard	Increase by 1%
- per 5°C below Standard	Decrease by 1%

END

DATE
FILMED
9-80

DTIC